Thesis/
Reports
Maloney,
T. M.
c. 1
DUP

# Composition Board from Standing Dead White Pine and Dead Lodgepole Pine

TS875
S96

**A cooperative research study by:**

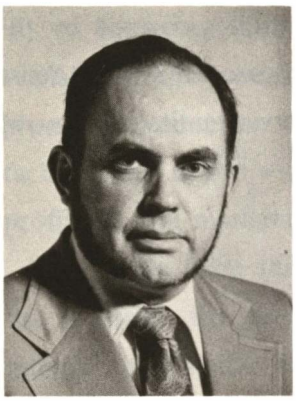
**Pacific Northwest Forest and Range Experiment Station**
**Rocky Mountain Forest and Range Experiment Station**
**Intermountain Forest and Range Experiment Station**
**Washington State University**

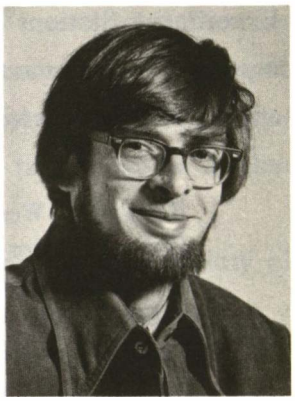
**Reprinted from:**

**Proceedings of the Tenth Washington State University Symposium on Particleboard March 1976, Pullman, Washington**

# Composition Board from Standing Dead White Pine and Dead Lodgepole Pine

THOMAS M. MALONEY, JOHN W. TALBOTT,
M. D. STRICKLER, and MARTIN T. LENTZ





Abstract

Dead trees of western white pine (Pinus monticola) and lodgepole pine (Pinus contorta), while normally unacceptable for plywood and with limited acceptance for lumber, constitute an important potential resource for wood construction materials in the form of dry-process composition boards. It was demonstrated that, even after standing dead many years, the wood of such trees changed very little from that of live trees in characteristics important to composition board manufacture. A wide spectrum of desirable particles, ranging from flakes to fiber, can be produced. Compatibility with commercial composition board resin appears to be retained, as determined by chemical tests of the wood and internal-bond strength tests.

It was concluded that the dead material of both white pine and lodgepole pine could be used effectively in various types of composition board. Some minor refinements of board-producing parameters are needed to optimize commercial board formulations, but these would be reasonable changes according to today's board technology. Suitable properties were found in almost all cases studied. Lodgepole pine composition boards had relatively poor linear expansion, exceeding commercial standards, except in flakeboards. It appeared that this was due to a species effect.

Of the particles studied, hammermilled, ring-cut flakes, atmospheric- and pressure-refined fiber appeared to be best. Drum-cut flakes were difficult to glue because of apparent surface quality damage due to flaking dry wood.

## Acknowledgements

This research is the result of studies conducted cooperatively by Washington State University, College of Engineering, and the U.S. Department of Agriculture, Forest Service. Forest products research units at the Pacific Northwest and Rocky Mountain Forest and Range Experiment Stations provided funding and sample material for the two studies covered by this report. The Intermountain Station's forest products unit helped fund the second study. Assistance given by the following project leaders of the cooperating Forest Service units is acknowledged.

Richard O. Woodfin, Jr.
Project Leader
Characterization and Utilization of Western Softwood Timber
and Forest Residue
Pacific Northwest Forest and Range Experiment Station
P. O. Box 3141
Portland, OR 97208

Harold E. Worth
Project Leader
Developing More Productive Uses for Forest Resources
Rocky Mountain Forest and Range Experiment Station
240 West Prospect St.
Fort Collins, CO 80521

Roland L. Barger
Program Manager
Improving Wood Resource Harvesting and Utilization
Intermountain Forest and Range Experiment Station
Forestry Sciences Laboratory
Drawer G
Missoula, MT 59801

The staff of the Bridger-Teton National Forest and the Clearwater National Forest provided helpful cooperation in the sampling phase of the work. This included help both in selecting and processing trees. Also, the assistance of Donald C. Markstrom of the Rocky Mountain Station was especially valuable.

## Introduction

This is the report of a joint study by the U.S. Forest Service and Washington State University concerning the suitability of the use of dead white pine and dead lodgepole pine for the manufacture of composition boards.

Large amounts of white and lodgepole pine, killed by disease, insects, and fire, are available in the western United States. Much of this type of timber is unsuitable for lumber or plywood production because of checking, weathering, and decay. Composition board manufacture may afford a means of extending the period of time in which such timber can be used in profitable and marketable building materials.

Aside from the obvious and important matters of amounts, location, and accessibility of the material, the practicability of such a scheme of utilization depends on the answers to a number of technical questions which can best be resolved in the laboratory.

## Objectives

The aim of the research was first to characterize the material on the basis of the quality, quantity, and uniformity of particles which can be milled from it by several types of commercial particle-generating equipment and to evaluate the compatibility of the generated particles with existing composition board resins, particularly urea-formaldehyde and phenol-formaldehyde.

Second, composition boards designed for specific uses (typical commercial boards) were to be produced and evaluated from the various particles generated. These two phases of research will be discussed separately in this paper.

# CHARACTERIZATION OF MATERIAL, PARTICLE GENERATION, AND RESIN COMPATIBILITY

## Experimental Outline

The following outline is presented to give the reader a concise overview of the form and scope of the first phase of work.

### Classification of the Material (classified and sampled by Forest Service personnel)

Species: 2

Western white pine
Lodgepole pine

Location in the tree: 2
Boles [over 8-in. (203 mm) diameter]
Tops (under 8-in. diameter)

Deterioration classes: 4 white pine + 5 lodgepole pine

A. Standing trees; recently dead; with "red" needles; most bark in place

B. Standing trees; no needles; bark retention 100 to 25%

C. Standing *old* dead trees; no needles, twigs, or small branches; deep checks and obvious weathering; bark retention up to 50% of merchantable bole

D. (Special class added for lodgepole only) *Down, old*, dead trees; no needles, twigs, or small branches; deep checks and obvious weathering; bark retention up to 20% of merchantable bole

E. Live controls

This makes 18 classes of material:
1 species (white pine) x 2 locations x 4 deterioration classes = 8

1 species (lodgepole) x 2 locations x 5 deterioration classes = 10

18 total

## Characterization of the Material Classes

### Physical

Specific Gravity: oven-dry weight/green (soaked) volume
Moisture content of logs as received (from sample disks)

### Biological

Amount of apparent decay
Sapstain

### Chemical (relates to resin compatibility)

Acidity (pH)
Buffering capacity

## Preparation of Particles (18 material classes x 5 particle types = 90 particle classes)

Bolts of each class split longitudinally in several pieces and randomly selected for:

Drum flaking (Hombak, at WSU)

Chipping (at WSU), then blended for randomization and separated into batches for:

Hammermilling (WSU)
Ring flaking (MKZ at Black Clawson Co., Everett, WA)
Atmospheric attrition milling to fiber (Bauer, at WSU)
Pressurized attrition milling (Bauer 418, CE Bauer, Springfield, OH)

Characterization of Particles

Direct

Photographs
Screen analysis where appropriate; amounts of "fines"
Slenderness ratios
Energy requirements: steam, electrical
Moisture content
Bulk density

Indirect (effects on board making)

Preparation of Simple Homogeneous Composition Boards from Three Particle Types

Particle types: 3 of the 5 types prepared
Hammermilled particles
Drum-cut flakes
Pressure-refined fiber

Material classes: 18

Resin types: 2
Liquid phenol-formaldehyde
Liquid urea-formaldehyde

Density: 2 levels (0.65 and 0.85 nominal specific gravity)

Replications: 2
18 classes x 3 particle types x 2 resins x 2 density levels x 2 replications = 432 boards

Characterization of Boards

Internal bond strength (IB) (Has implications on resin compatibility)

Bending tests

Modulus of rupture (MOR)

Modulus of elasticity (MOE)

24-hour water soak

Linear expansion (LE)

## Sampling

Wood for the project was sampled according to a plan developed by the Forest Service. Data on the sampling plan are available for those interested. The white pine came from north Idaho and the lodgepole pine, from Wyoming.

The material was supplied in roundwood bolts three to five feet long (1 to 1.5 m) with the bark on. A disk, cut from the top end of each bolt and correspondingly numbered and protected by a plastic bag, was supplied to allow determination of moisture content and specific gravity of the corresponding bolts. An additional disk was cut from each bolt at the laboratory and sanded to allow photographs and visual estimation of the percentage of decay.

## Description of Wood Materials

### Tree Size

The sampled wood was about 8 to 15 in. (203 to 381 mm) dbh for the white pine and 7 to 25 in. (178 to 635 mm) dbh for the lodgepole pine. These sizes are representative of the available dead timber in each area.

### Amount of Bark

Bark retention, as mentioned under "Experimental Plan," was one of the criteria for determining the deterioration class of the material. It ranged from 100% retention in the live trees, through nearly total retention in the A class, to a very variable retention in the B, C, and D classes—many individual bolts, especially in the tops, having no bark present. The amount of bark entering the furnish of a composition board plant can affect the appearance and properties of the product. This sampled material, however, was harvested carefully by hand and would be expected to retain much more bark, particularly in the dead classes, than it would under commercial harvesting conditions. Thus, no precise quantification of bark content by weight was attempted. No bark was deliberately removed in the particle-making or board-making phases of the experiment, although some fell off in handling. It was estimated that about 10%, by weight, of bark entered the furnish in the live control classes and the A classes and probably less than 5% in the B, C, and D classes.

## Specific Gravity and Moisture Content

Moisture content and specific gravity values are class averages weighted according to the calculated dry weights of the individual bolts corresponding to the sampled disks (Table 1). The specific gravity of the live white pine (0.39) is a little higher than the species average (0.37) published in the Wood Handbook (1), while the lodgepole pine (at 0.37) is slightly lower than the published species average (0.38).

The differences between the specific gravities of the live material and those of the corresponding deterioration classes can be interpreted as density loss due to decay and other deterioration. The density losses so measured, however, may tend to underestimate the amount of weight loss from decay, because the volume used in the calculation was based on water displacement—which gives not the gross volume but automatically subtracts the volume of decay voids penetrated by the water.

Only in white pine is there appreciably lower specific gravity in dead material than in live—the A and B deterioration classes being about 5% lower and the C class about 14% lower.

The weighted class averages of moisture content (Table 1) show that all the dead material averaged below fiber saturation with the exception of the class A white pine (red needles and 100% bark retention), which was just above fiber saturation. The moisture content of the live white pine averaged about 94%. Elapsed time and loss of bark after death of the trees allowed the moisture content to fall to 32%, 20%, and 15% in the A, B, and C classes, respectively. The lodgepole pine started with a higher live moisture content (110%) but fell to 21%, 12%, and 13% in the A, B, and C classes. The D class (down dead) lodgepole was 24%—reflecting the more moist conditions and less air movement at or near ground level.

Moisture content of the wood resource has an important bearing on several aspects of the composition board process. Lower moisture content, of course, means lower transportation and drying costs. If the moisture content is well below fiber saturation, chips can be stored under cover for long periods with little deterioration. In the different particle-generating processes, the moisture content can profoundly affect both the quality of particles and the power required in their generation, as will be discussed later. It can be noted at this point, however, that in normal operations raw material with lower moisture content is more difficult to mill or cut into quality particles.

## Visible Deterioration

Visible deterioration of the dead material includes bark loss, checking, weathering, sapstain, saprot, and heartrot.

Table 1. Characteristics of Log Materials as Received (Weighted Class Means).

| Species | | Deterioration Class | Top or[1] Bole | Moisture[2] Content % | Specific[3] Gravity | Visible Decay % |
|---|---|---|---|---|---|---|
| White Pine | Standing Dead | A Red needles, bark mostly intact | B | 32 | 0.37 | 1.4 |
| | | | T | 32 | 0.36 | 0.0 |
| | | B No needles | B | 19 | 0.38 | 0.2 |
| | | | T | 22 | 0.36 | 0.0 |
| | | C Deep checks, weathering. No: twigs, small branches | B | 18 | 0.34 | 0.4 |
| | | | T | 14 | 0.33 | 2.3 |
| | Live | L Living trees | B | 87 | 0.39 | 0.0 |
| | | | T | 97 | 0.39 | 0.0 |
| Lodgepole Pine | Standing Dead | A As above | B | 21 | 0.37 | < 0.1 |
| | | | T | 21 | 0.37 | 0.0 |
| | | B As above | B | 13 | 0.36 | 0.0 |
| | | | T | 12 | 0.37 | < 0.1 |
| | | C As above | B | 13 | 0.38 | 0.2 |
| | | | T | 13 | 0.38 | 0.3 |
| | Down | D Same as C but not standing | B | 24 | 0.38 | 0.2 |
| | | | T | 24 | 0.38 | 0.5 |
| | Live | L Living trees | B | 99 | 0.37 | 0.0 |
| | | | T | 123 | 0.37 | 0.0 |
| Means | | White Pine | | | 0.36 | 0.5 |
| | | Lodgepole Pine | | | 0.37 | 0.14 |
| | | Both | | | 0.36 | 0.32 |

Notes:
1. Bole = greater than 8 in. diameter (203 mm)
   Top = less than 8 in. diameter
2. Oven-dry basis
3. Oven-dry weight and green (soaked) volume

The loss of bark is beneficial with current commercial composition board practice. The amount present in this material, however, would be expected to have little effect on mechanical properties.

The progressive checking and weathering after the death of the tree is shown in the photograph of bolts and disks from a typical tree of B class white pine (Figure 1). Wood surfaces exposed to weather undergo degradative changes under the action of light, moisture, and atmospheric oxygen, which soon render the exposed surface unsuitable for gluing. Prolonged weathering results in gradual loss of wood material from the surface. The amount of weathered surface on the circumference and within checks is very small in relation to the large amount of new surface generated in any current particle-generation method. Thus, the random distribution of this small proportion of degraded surface throughout the volume of a composition board should have only minor effect on properties.

Sapstain, or bluestain, was present in most of the sapwood of the dead material. The fungus causing sapstain lives on the sugars and other nonstructural materials remaining from the living cells of the sapwood and does not significantly attack the cell walls. The strength of wood usually is considered to be unaffected by sapstain. A four-month unavoidable delay in preparing the pressure-refined fiber allowed the sapstain to develop in the chips of the live classes of material as well. Thus, the flakes and hammermilled particles of the live classes are the only classes having no sapstain.

None of the dead classes of material were entirely free from heartrot and saprot decay, although many individual bolts and some trees were free from visible decay. The sanded surfaces of the discs cut from the bolts were examined visually and by a "thumbnail" test, and the apparent amount of decayed material estimated. Class averages of percent visible decay (Table 1), weighted according to the oven-dry weights of the bolts, show surprisingly little total decay. There was no consistent pattern of distribution of apparent decay among the A, B, and C classes of supposed increasing deterioration nor between tops and boles.

The only classes having more than one percent of apparent decay occurred in white pine and were the A class boles (1.4%) and the C class tops (2.3%). Most of the decayed material was confined to a very few rather heavily decayed bolts, rather than being distributed in small amounts throughout.

The relatively small amount of visible decay compared to the noticeable density deficit in the dead white pine material would indicate the possible presence of considerable decay in a degree causing some weight loss but still not readily apparent visually.

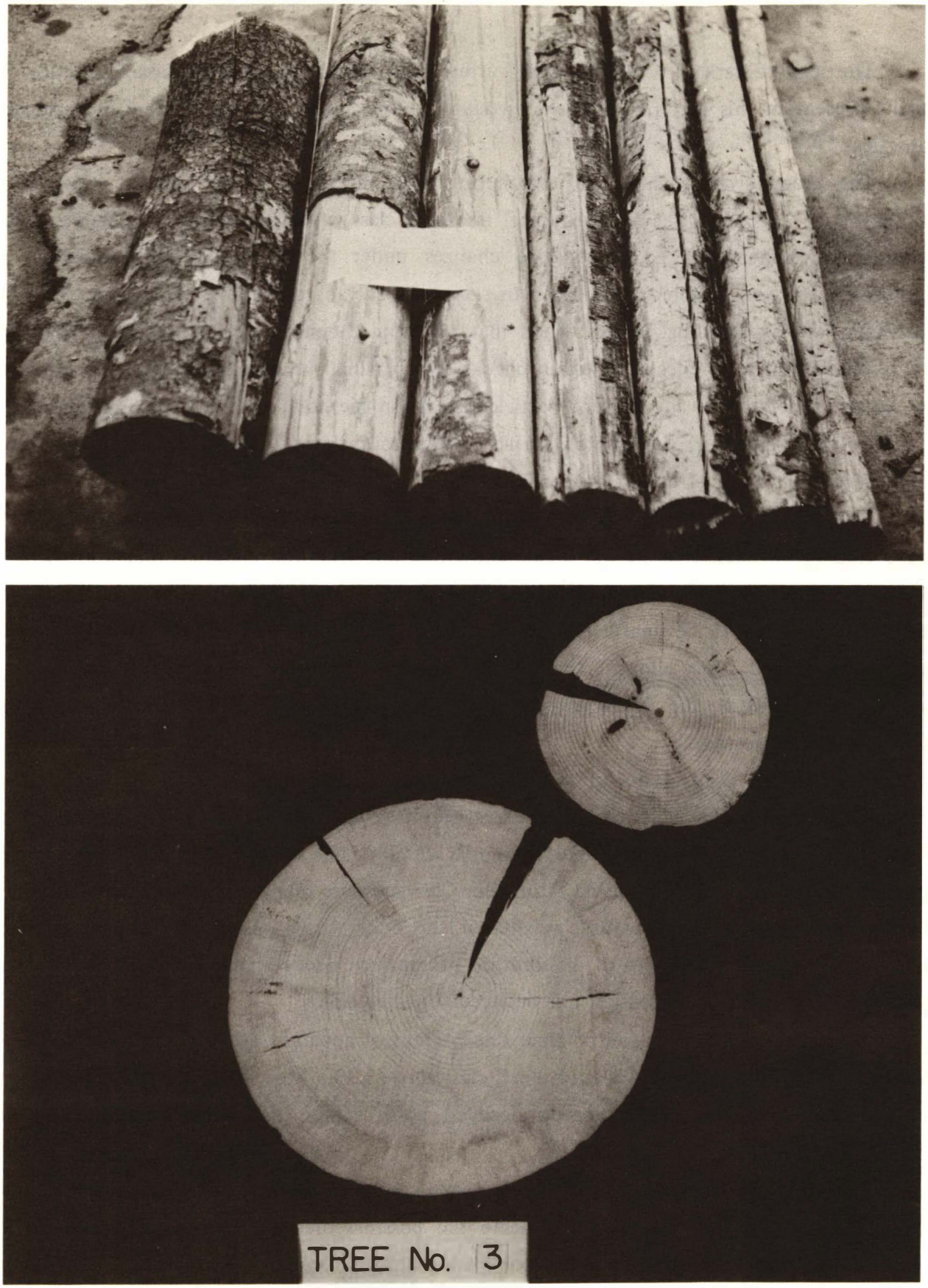



Figure 1. Typical B Class White Pine Bolts and Discs.

### Straightness of Grain

The geometry and mechanical properties of hammermilled particles, fibers, or flakes prepared from chips are affected little by grain deviation in the timber, which would cause large strength losses in sawn lumber. Such grain deviation from knots, spiral grain, and crooked stems, however, can have a decided effect on the geometry and effective grain length of flakes prepared from roundwood by a drum flaker.

Very little spiral grain was apparent in any of the classes of dead wood, where it would have been revealed by the extensive checking. It can be assumed that the live material was similar in this respect.

The top classes or higher portions of the stem would be expected to have more knots with associated grain deviation than would the boles or lower portions.

## Characterization of Particles

There are many characteristics of particles and particle-making processes which affect the properties and the economics of composition board. The term particle geometry usually refers to the size and shape of particles and the relation of the grain direction to the principal axes of the particles. Important characteristics which derive from particle geometry are slenderness ratio, bulk density, and specific surface. It is not always practical or appropriate to measure all these aspects of geometry for all particle types. The energy or power requirement for generation of particles, measured whenever possible in this study, can be an important item of cost in composition board manufacturing.

### Particle Preparation Procedures

All particles were made from the different classes of material at the moisture content as received—as would probably be done commercially. It would have been desirable to have made particles also from materials brought to a common moisture content to avoid confounding of the effects of moisture content and deterioration class on particle characteristics, but this was precluded by budget limitations.

Because all of the planned particle-generating methods, except the drum flaking, required chips as starting material, all the bolts of each deterioration class were divided longitudinally into several pieces by splitting or bandsawing. One piece from each bolt then was selected at random

and reserved for drum flaking. The rest of the material for each class then was chipped, thoroughly mixed or randomized, and divided into four lots. The material was stored in plastic bags to maintain the moisture content until the actual particle-generating steps were completed.

Energy requirements in kWh per oven-dry (OD) ton for particle generation were measured for the hammermilling, drum flaking, and atmospheric and pressurized attrition milling. No provision for power measurement was available for the ring-flaker operation, which was done at Black Clawson Inc. in Everett, Washington. Black Clawson engineers, however, estimate about 28 kWh per OD ton (31 kWh per OD metric ton) for cutting flakes 0.024 in. (0.61 mm) in flake thickness. The pressurized attrition milling used, in addition to the measured electrical power, a very substantial but unmeasured amount of energy in the required process steam. This was estimated at 470 kWh/ODT (518 kWh/OD metric ton) by CE Bauer engineers. Presteaming of chips for the atmospheric attrition milling also required substantial amounts of steam.

Power requirement for the chipping was not measured but was estimated by Black-Clawson engineers for material of this size as approximately 7 kWh per OD ton (7.7 kWh per OD metric ton).

Details of procedure applicable to specific particle-generation methods are included with particle descriptions under corresponding particle-type headings.

Hammermilling: Chips of all classes were milled without drying in a Prater[1] Bluestreak No. 15 hammermill, using a screen plate with 1/4-in. (6.4 mm) diameter round holes. Photographs comparing hammermilled particles from live and dead classes of both species are shown in Figures 2 and 3. Characteristics of the hammermilled particles analyzed according to species, deterioration class, and location in the tree (top or bole) are summarized in Table 2.

The main differences found are probably more closely related to moisture content at milling than to any other factors associated with the deterioration classes. This would be expected because of the very small amounts of decay present.

The energy required in hammermilling ranged from 28 to 149 kWh per OD ton and was closely correlated with moisture content of the chips—higher moisture content requiring more energy. There was no noticeable difference in energy requirement between the two species.

Bulk density of the hammermilled particles ranged from 6.5 to 14.1 lbs per cu ft (47.2 to 102.5 kg per cu m) and was negatively correlated with moisture content—high moisture content resulting in lower bulk density. There appears to be a real difference in particle bulk density between the two species in the dead materials:

---

[1]The use of trade firm or corporation names in this publication is for the information and convenience of the reader and does not constitute an official endorsement or approval by the U.S. Department of Agriculture.

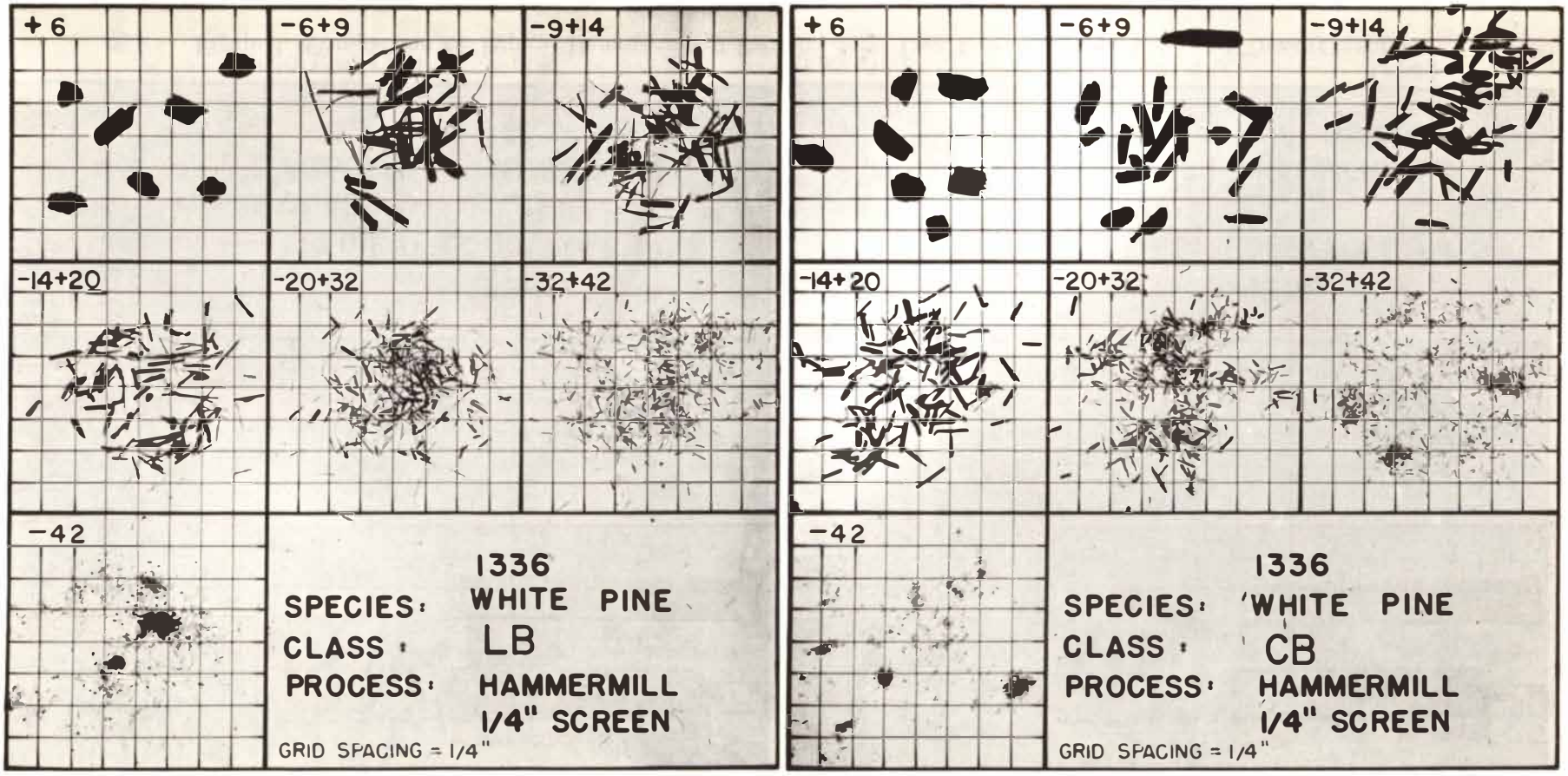



Figure 2. Comparison of Typical Hammermilled Particles from Live Trees (Class L) and Dead Trees (Class C).

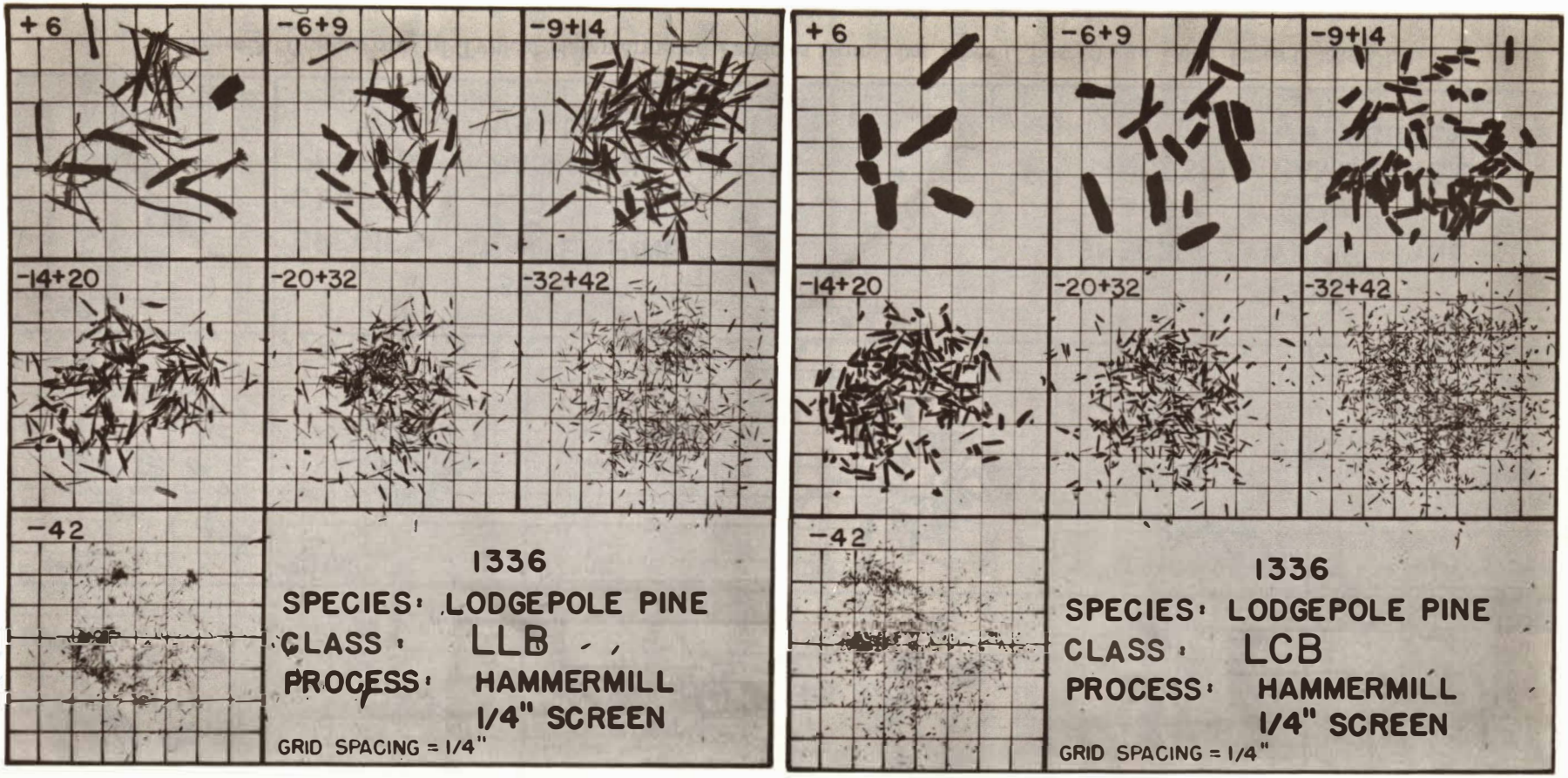



Figure 3. Comparison of Typical Hammermilled Particles from Live Trees (Class L) and Dead Trees (Class C).



Table 2. Characteristics of Hammermilled Particles.

Table 2. Characteristics of Hammermilled Particles.

| Species | | Deterioration Class | Top or Bole | Moisture Content of Chips % | Energy kWh/ODT | Bulk Density lb/cu ft | Slenderness Ratio L/T | Fines % (-42 Tyler) |
|---|---|---|---|---|---|---|---|---|
| White Pine | Standing Dead | A Red needles, bark mostly intact | B | 31 | 97 | 9.3 | 10 | 2.0 |
| | | | T | 22 | 63 | 10.7 | 8 | 2.0 |
| | | B No needles | B | 11 | 38 | 11.3 | 10 | 4.8 |
| | | | T | 9 | 35 | 11.2 | 10 | 9.3 |
| | | C Deep checks, weathering. No: twigs, small branches | B | 9 | 36 | 10.4 | 10 | 5.3 |
| | | | T | 8 | 33 | 9.6 | 10 | 6.5 |
| | Live | L Living trees | B | 56 | 149 | 6.5 | 11 | 2.8 |
| | | | T | 72 | 108 | 7.1 | 10 | 2.0 |
| Lodgepole Pine | Standing Dead | A As above | B | 23 | 71 | 9.8 | 6 | 1.0 |
| | | | T | 15 | 37 | 13.3 | 7 | 3.2 |
| | | B As above | B | 12 | 35 | 12.4 | 6 | 3.7 |
| | | | T | 14 | 28 | 13.4 | 7 | 5.5 |
| | | C As above | B | 14 | 35 | 12.7 | 8 | 3.5 |
| | | | T | 9 | 28 | 14.1 | 8 | 5.3 |
| | Down | D Same as C but not standing | B | 21 | 50 | 13.2 | 6 | 3.0 |
| | | | T | 18 | 38 | 13.4 | 7 | 7.3 |
| | Live | L Living trees | B | 73 | 134 | 6.6 | 7 | 4.3 |
| | | | T | 78 | 104 | 7.1 | 9 | 3.6 |
| Means | | White Pine | | | 70 | 9.5 | 10 | 4.4 |
| | | Lodgepole Pine | | | 56 | 11.6 | 7 | 4.0 |
| | | Both | | | 63 | 10.5 | 8.5 | 4.2 |

| Name | lbs/cu ft | kg/cu m |
|---|---|---|
| Dead lodgepole pine | 12.8 | 205 |
| Live lodgepole | 6.8 | 109 |
| Dead white pine | 10.4 | 167 |
| Live white pine | 6.8 | 109 |

The amount of fines (passing through a Tyler No. 42 screen) developed in hammermilling ranged from 2% to 9.3% and appeared to be related primarily to moisture content–the drier the material, the more fines–and not related to species. Figure 4 plots average Tyler screen analyses for the two species, with the live classes shown in solid lines and the dead classes dotted.

The slenderness ratio of a random sample of particles from each screen fraction was measured, and weighted averages for each class are shown in the next-to-last column of Table 2. The values range from 6 to 11 and appear to be unrelated to age, class, or moisture content but averaged slightly higher for the white pine (9.7) than for the lodgepole pine (7.1). This is compatible with the bulk density difference between species noted above. This rather low range of length-to-thickness ratio is typical of hammermilled particles and would be expected to contribute high internal bond strength, but only moderate bending properties, to composition boards. They are slender enough to afford good alignment in an electric field. It should be noted, however, that extensive experimentation was not conducted on hammermilling. By using slotted screens, it has been found that particles with a better slenderness ratio can be developed, and this should be considered by anyone wanting to use this type of material in a board plant.

Drum Flaking: Whole wood for drum flaking was selected randomly from the split sections of bolts, as mentioned previously, to secure representative material for each class. These pieces were flaked in a Hombak PRZ drum flaker with head dimensions of 14-in. (356 mm) diameter and 7-in. (178 mm) axial length. Flaking and scoring knives were arranged to cut flakes about 1.125 in. (28.6 mm) long. The feed rate was set at 0.025 in. (0.64 mm) per knife at the head centerline; but, as the 10-in. (254 mm) width of the feed chute subtended about $90^{o}$ of arc at the head circumference, the theoretical flake thickness varied from 0.025 in. (0.64 mm) at the center to $0.025/\sqrt{2}$, or 0.018 in. (0.46 mm), at the chute edges. The actual thickness range was from about 0.012 to 0.030 in. (0.30 to 0.76 mm), with the distribution peak at about 0.020 in. (0.51 mm) corresponding to a length/thickness ratio of 56 for flakes unbroken in length. The thickness distribution peaked more sharply and the surfaces were smoother for the live material with its higher moisture content than for the dead material.

The width of flake is not controlled directly and ranged from narrow splinters to several inches as flaked. The very wide flakes tended to split along the grain on drying and handling to

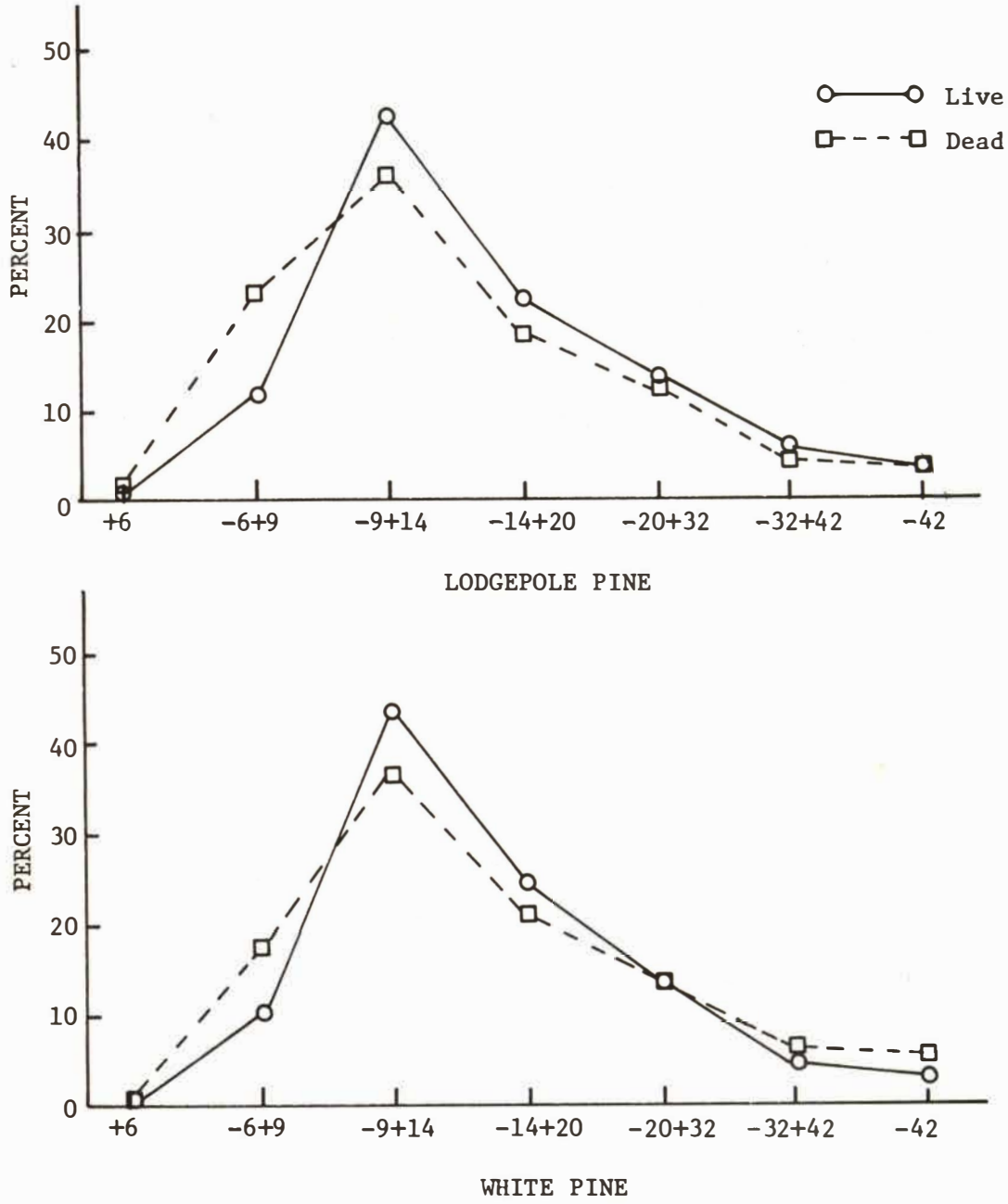



Figure 4. Tyler Screen Analyses of Hammermilled Particles.

form narrower flakes with an aspect ratio (width/length) less than one. Flakes from the live material were wider and more flexible than those from the dead material and tended to become folded along the grain and to become set in this condition in the dryer. This folding resulted in significant numbers of wide flake surfaces remaining uncoated with resin in the blending operation, which in turn gave low and erratic internal bond strengths. To avoid this and to correspond more nearly to commercial practice, extra flakes from the live material were given a mild secondary milling in the hammermill, with the screen removed, after drying to reduce the flake width. Figures 5 and 6 show comparisons of typical flakes from live and dead material from both species, while Figure 7 illustrates flakes from live material before and after the secondary milling. Both types were included in the board-making and internal bond tests reported in a following section.

The flakes after drying were subjected to the action of an air classifier to remove over-thick material, chunks (mostly from knots), dust, and fines. The amount of fines removed (Table 3) ranged from 1.9% to 6.6%—being least for the live material, which was over fiber saturation when flaked. The amount of heavy material removed in air classification ranged from 5% to 16.1%. In the live classes, this consisted mostly of material from knots; but in the dead classes, it also contained many heavy splinters.

Bulk density ranged from 3.7 to 4.4 lbs per cu ft (59 to 70 kg per cu m) for the live classes and from 4.6 to 6.3 lbs per cu ft (74 to 101 kg per cu m) for the dead classes.

Energy requirements for flaking ranged from 10 to 15 kWh per oven-dry ton (11 to 16.5 kWh per over-dry metric ton) and appeared to be independent of moisture content. The average value was 12 kWh per oven-dry ton (13.2 kWh per oven-dry metric ton), which was the least energy consumption of any of the particle preparation methods.

Ring-Flaking: An alternative to the drum flaker is the ring-flaker, which makes flakes from previously prepared chips, hogged material, etc. In this method the flake length in the grain direction is limited by the grain length of the chips, which in turn is controlled by the knife setting of the chipper. The flake width tends to be narrower than with the drum flaker—being limited by splitting along the grain which occurs in the chipper. Only the flake thickness is controlled fairly closely by the knife settings, ring size, and model of the flaker and its particular operating characteristics.

Undried chips of all the classes of material were flaked in a MKZ flaker, Model 14, located at the Black Clawson Company headquarters in Everett, Washington. The flakes were returned to the laboratory at WSU, where they were dried. The characteristics of these flakes are shown in Table 4. Photographs comparing ring-cut flakes from live and dead classes of both species are shown in Figures 8 and 9.

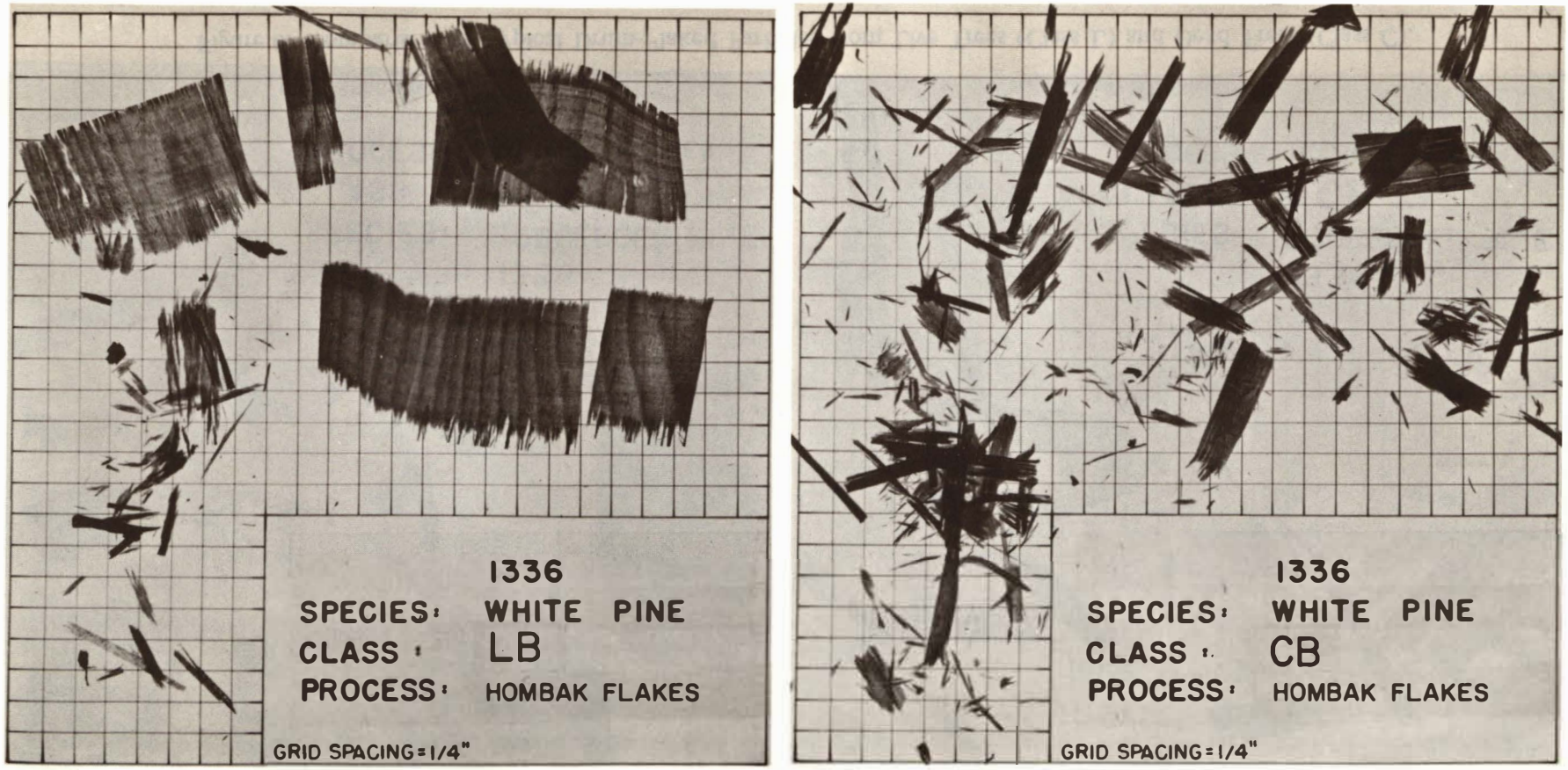



Figure 5. Comparison of Typical Drum-Flaked Particles from Live Trees (Class L) and Dead Trees (Class C).

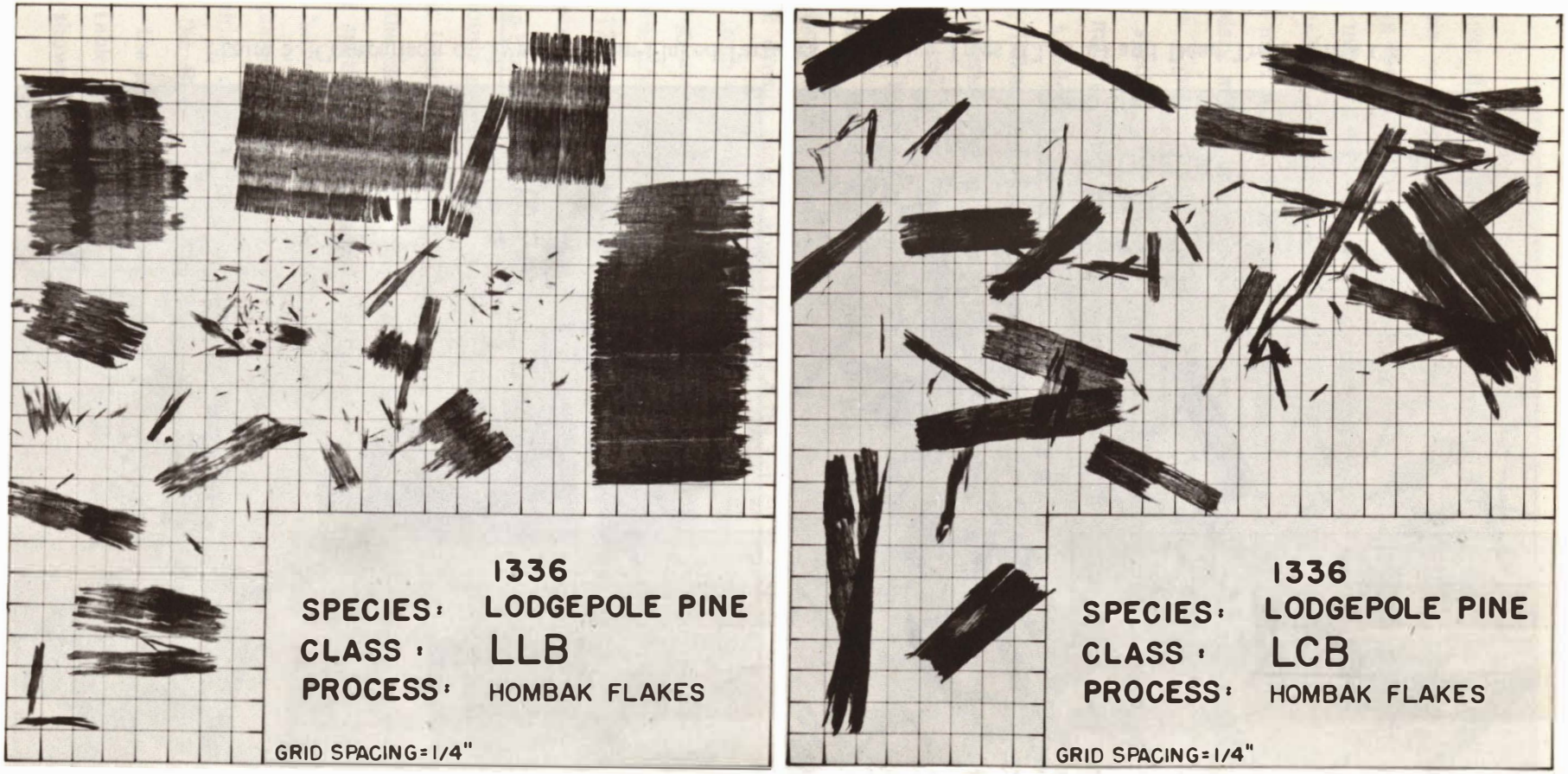



Figure 6. Comparison of Typical Drum-Flaked Particles from Live Trees (Class L) and Dead Trees (Class C).

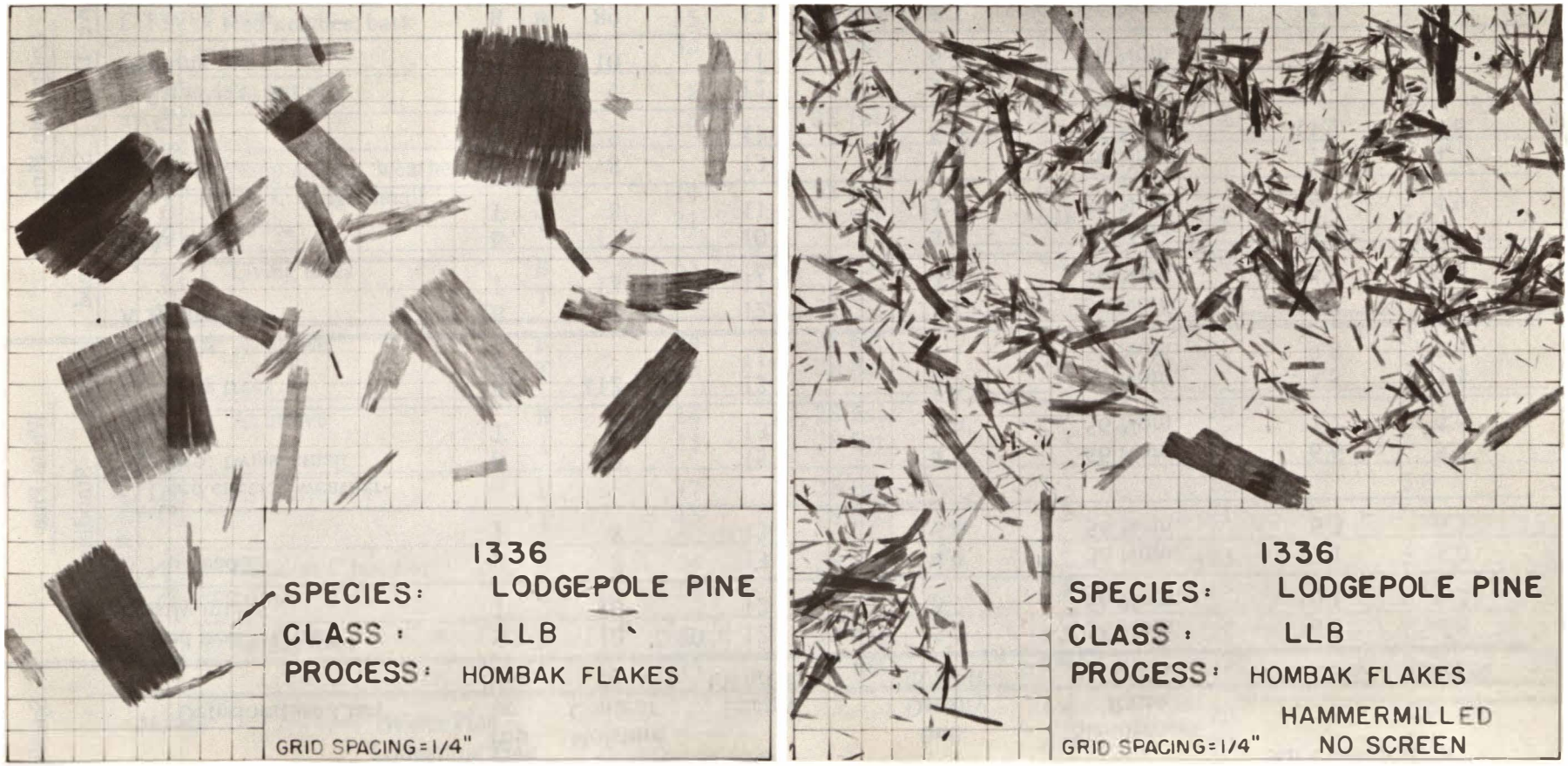



Figure 7. Comparison of Typical Drum-Flaked Particles from Live Trees (Class L) before and after Hammermilling.

Table 3. Characteristics of Flakes Prepared by Drum Flaker.

| Species | | Deterioration Class | Top or Bole | Moisture Content % | Energy kWh/ODT | Bulk Density lb/cu ft | Slenderness Ratio L/T | Air Classification Coarse % | Air Classification Fines % |
|---|---|---|---|---|---|---|---|---|---|
| White Pine | Standing Dead | A Red needles, bark mostly intact | B | 10 | 12 | 5.2 | 56 Nom. | 16.1 | 4.8 |
| | | | T | 10 | 12 | 5.7 | 56 Nom. | 10.1 | 6.2 |
| | | B No needles | B | 8 | 13 | 4.9 | 56 Nom. | 12.1 | 5.0 |
| | | | T | 8 | 13 | 5.0 | 56 Nom. | 6.3 | 6.3 |
| | | C Deep checks, weathering. No: twigs, small branches | B | 8 | 15 | 4.8 | 56 Nom. | 6.6 | 5.9 |
| | | | T | 8 | 13 | 4.6 | 56 Nom. | 7.2 | 4.6 |
| | Live | L Living trees | B | 112 | 13 | 3.7 | 56 Nom. | 5.5 | 3.1 |
| | | | T | - | 11 | 4.1 | 56 Nom. | 9.8 | 3.8 |
| Lodgepole Pine | Standing Dead | A As above | B | 14 | 12 | 5.1 | 56 Nom. | 8.4 | 3.4 |
| | | | T | 13 | 11 | 4.9 | 56 Nom. | 8.6 | 4.6 |
| | | B As above | B | 11 | 10 | 4.7 | 56 Nom. | 12.2 | 3.7 |
| | | | T | 8 | 11 | 5.5 | 56 Nom. | 8.2 | 4.9 |
| | | C As above | B | 8 | 13 | 5.0 | 56 Nom. | 7.1 | 4.7 |
| | | | T | 9 | 11 | 6.0 | 56 Nom. | 11.2 | 4.6 |
| | Down | D Same as C but not standing | B | 9 | 12 | 5.3 | 56 Nom. | 7.8 | 6.0 |
| | | | T | 10 | 11 | 6.3 | 56 Nom. | 9.7 | 6.6 |
| | Live | L Living trees | B | 89 | 12 | 4.3 | 56 Nom. | 5.0 | 2.9 |
| | | | T | 46 | 11 | 4.4 | 56 Nom. | 6.7 | 1.9 |
| Means | | White Pine | | | 13 | 4.75 | | 9.2 | 4.9 |
| | | Lodgepole Pine | | | 11 | 5.15 | | 8.5 | 4.3 |
| | | Both | | | 12 | 4.95 | | 8.8 | 4.6 |

Table 3. Characteristics of Flakes Prepared by Drum Flaker.

| Species | | Deterioration Class | Top or Bole | Moisture Content % | Energy kWh/ODT | Bulk Density lb/cu ft | Slenderness Ratio L/T | Air Classification Coarse % | Air Classification Fines % |
|---|---|---|---|---|---|---|---|---|---|
| White Pine | Standing Dead | A Red needles, bark mostly intact | B | 10 | 12 | 5.2 | 56 Nom. | 16.1 | 4.8 |
| | | | T | 10 | 12 | 5.7 | 56 Nom. | 10.1 | 6.2 |
| | | B No needles | B | 8 | 13 | 4.9 | 56 Nom. | 12.1 | 5.0 |
| | | | T | 8 | 13 | 5.0 | 56 Nom. | 6.3 | 6.3 |
| | | C Deep checks, weathering. No: twigs, small branches | B | 8 | 15 | 4.8 | 56 Nom. | 6.6 | 5.9 |
| | | | T | 8 | 13 | 4.6 | 56 Nom. | 7.2 | 4.6 |
| | Live | L Living trees | B | 112 | 13 | 3.7 | 56 Nom. | 5.5 | 3.1 |
| | | | T | - | 11 | 4.1 | 56 Nom. | 9.8 | 3.8 |
| Lodgepole Pine | Standing Dead | A As above | B | 14 | 12 | 5.1 | 56 Nom. | 8.4 | 3.4 |
| | | | T | 13 | 11 | 4.9 | 56 Nom. | 8.6 | 4.6 |
| | | B As above | B | 11 | 10 | 4.7 | 56 Nom. | 12.2 | 3.7 |
| | | | T | 8 | 11 | 5.5 | 56 Nom. | 8.2 | 4.9 |
| | | C As above | B | 8 | 13 | 5.0 | 56 Nom. | 7.1 | 4.7 |
| | | | T | 9 | 11 | 6.0 | 56 Nom. | 11.2 | 4.6 |
| | Down | D Same as C but not standing | B | 9 | 12 | 5.3 | 56 Nom. | 7.8 | 6.0 |
| | | | T | 10 | 11 | 6.3 | 56 Nom. | 9.7 | 6.6 |
| | Live | L Living trees | B | 89 | 12 | 4.3 | 56 Nom. | 5.0 | 2.9 |
| | | | T | 46 | 11 | 4.4 | 56 Nom. | 6.7 | 1.9 |
| Means | | White Pine | | | 13 | 4.75 | | 9.2 | 4.9 |
| | | Lodgepole Pine | | | 11 | 5.15 | | 8.5 | 4.3 |
| | | Both | | | 12 | 4.95 | | 8.8 | 4.6 |

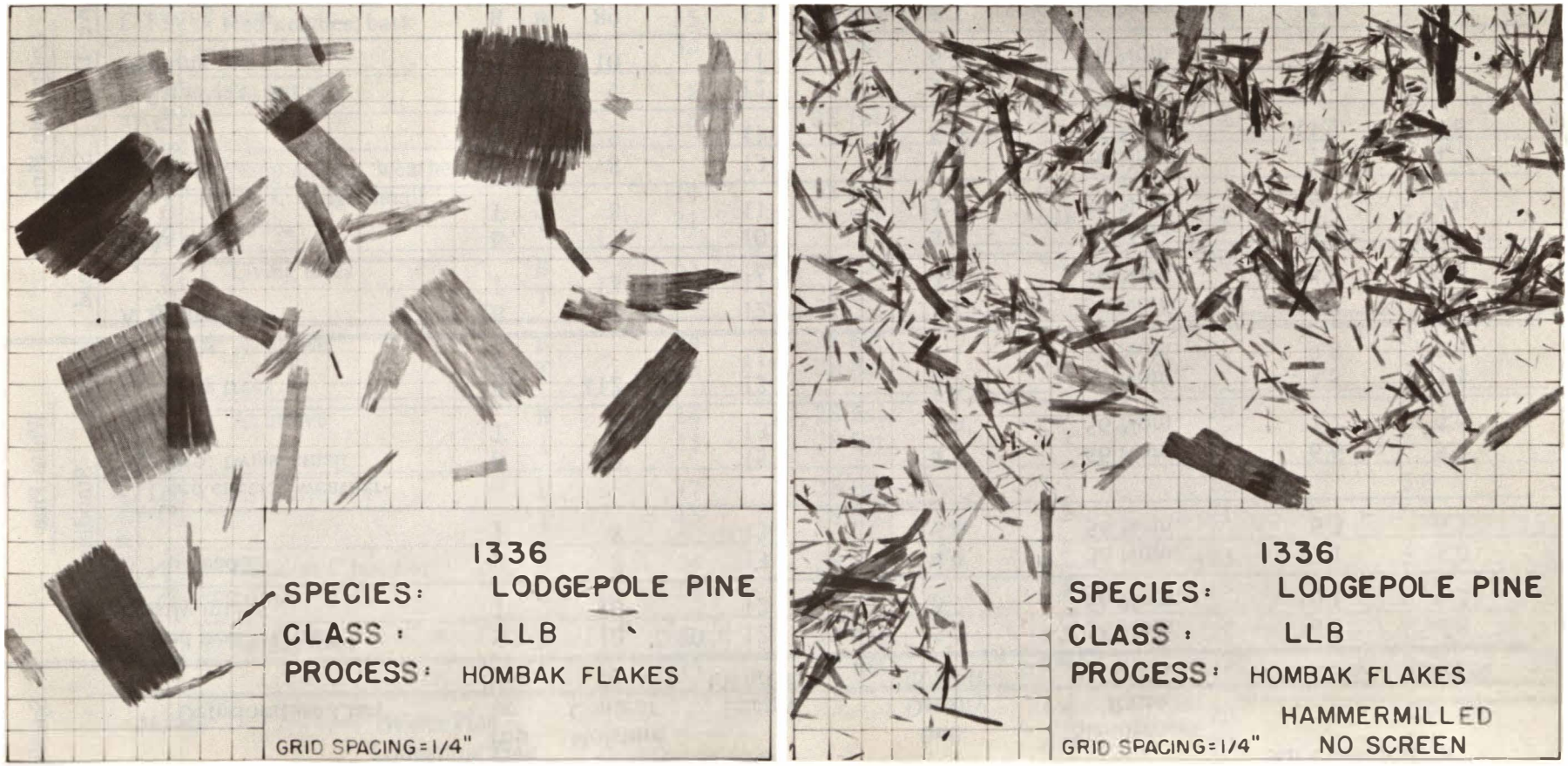



Figure 7. Comparison of Typical Drum-Flaked Particles from Live Trees (Class L) before and after Hammermilling.

Table 3. Characteristics of Flakes Prepared by Drum Flaker.

| Species | | Deterioration Class | Top or Bole | Moisture Content % | Energy kWh/ODT | Bulk Density lb/cu ft | Slenderness Ratio L/T | Air Classification Coarse % | Air Classification Fines % |
|---|---|---|---|---|---|---|---|---|---|
| White Pine | Standing Dead | A Red needles, bark mostly intact | B | 10 | 12 | 5.2 | 56 Nom. | 16.1 | 4.8 |
| | | | T | 10 | 12 | 5.7 | 56 Nom. | 10.1 | 6.2 |
| | | B No needles | B | 8 | 13 | 4.9 | 56 Nom. | 12.1 | 5.0 |
| | | | T | 8 | 13 | 5.0 | 56 Nom. | 6.3 | 6.3 |
| | | C Deep checks, weathering. No: twigs, small branches | B | 8 | 15 | 4.8 | 56 Nom. | 6.6 | 5.9 |
| | | | T | 8 | 13 | 4.6 | 56 Nom. | 7.2 | 4.6 |
| | Live | L Living trees | B | 112 | 13 | 3.7 | 56 Nom. | 5.5 | 3.1 |
| | | | T | - | 11 | 4.1 | 56 Nom. | 9.8 | 3.8 |
| Lodgepole Pine | Standing Dead | A As above | B | 14 | 12 | 5.1 | 56 Nom. | 8.4 | 3.4 |
| | | | T | 13 | 11 | 4.9 | 56 Nom. | 8.6 | 4.6 |
| | | B As above | B | 11 | 10 | 4.7 | 56 Nom. | 12.2 | 3.7 |
| | | | T | 8 | 11 | 5.5 | 56 Nom. | 8.2 | 4.9 |
| | | C As above | B | 8 | 13 | 5.0 | 56 Nom. | 7.1 | 4.7 |
| | | | T | 9 | 11 | 6.0 | 56 Nom. | 11.2 | 4.6 |
| | Down | D Same as C but not standing | B | 9 | 12 | 5.3 | 56 Nom. | 7.8 | 6.0 |
| | | | T | 10 | 11 | 6.3 | 56 Nom. | 9.7 | 6.6 |
| | Live | L Living trees | B | 89 | 12 | 4.3 | 56 Nom. | 5.0 | 2.9 |
| | | | T | 46 | 11 | 4.4 | 56 Nom. | 6.7 | 1.9 |
| Means | | White Pine | | | 13 | 4.75 | | 9.2 | 4.9 |
| | | Lodgepole Pine | | | 11 | 5.15 | | 8.5 | 4.3 |
| | | Both | | | 12 | 4.95 | | 8.8 | 4.6 |

Table 3. Characteristics of Flakes Prepared by Drum Flaker.

| Species | | Deterioration Class | Top or Bole | Moisture Content % | Energy kWh/ODT | Bulk Density lb/cu ft | Slenderness Ratio L/T | Air Classification Coarse % | Air Classification Fines % |
|---|---|---|---|---|---|---|---|---|---|
| White Pine | Standing Dead | A Red needles, bark mostly intact | B | 10 | 12 | 5.2 | 56 Nom. | 16.1 | 4.8 |
| | | | T | 10 | 12 | 5.7 | 56 Nom. | 10.1 | 6.2 |
| | | B No needles | B | 8 | 13 | 4.9 | 56 Nom. | 12.1 | 5.0 |
| | | | T | 8 | 13 | 5.0 | 56 Nom. | 6.3 | 6.3 |
| | | C Deep checks, weathering. No: twigs, small branches | B | 8 | 15 | 4.8 | 56 Nom. | 6.6 | 5.9 |
| | | | T | 8 | 13 | 4.6 | 56 Nom. | 7.2 | 4.6 |
| | Live | L Living trees | B | 112 | 13 | 3.7 | 56 Nom. | 5.5 | 3.1 |
| | | | T | - | 11 | 4.1 | 56 Nom. | 9.8 | 3.8 |
| Lodgepole Pine | Standing Dead | A As above | B | 14 | 12 | 5.1 | 56 Nom. | 8.4 | 3.4 |
| | | | T | 13 | 11 | 4.9 | 56 Nom. | 8.6 | 4.6 |
| | | B As above | B | 11 | 10 | 4.7 | 56 Nom. | 12.2 | 3.7 |
| | | | T | 8 | 11 | 5.5 | 56 Nom. | 8.2 | 4.9 |
| | | C As above | B | 8 | 13 | 5.0 | 56 Nom. | 7.1 | 4.7 |
| | | | T | 9 | 11 | 6.0 | 56 Nom. | 11.2 | 4.6 |
| | Down | D Same as C but not standing | B | 9 | 12 | 5.3 | 56 Nom. | 7.8 | 6.0 |
| | | | T | 10 | 11 | 6.3 | 56 Nom. | 9.7 | 6.6 |
| | Live | L Living trees | B | 89 | 12 | 4.3 | 56 Nom. | 5.0 | 2.9 |
| | | | T | 46 | 11 | 4.4 | 56 Nom. | 6.7 | 1.9 |
| Means | | White Pine | | | 13 | 4.75 | | 9.2 | 4.9 |
| | | Lodgepole Pine | | | 11 | 5.15 | | 8.5 | 4.3 |
| | | Both | | | 12 | 4.95 | | 8.8 | 4.6 |

Table 4. Characteristics of Flakes Prepared by Ring Flaker.

| Species | | Deterioration Class | Top or Bole | Moisture Content of Chips % | Energy kWh/ODT | Bulk Density lb/cu ft | Slenderness Ratio L/T | Fines % (-42% Tyler) |
|---|---|---|---|---|---|---|---|---|
| White Pine | Standing Dead | A Red needles, bark mostly intact | B | 35 | 28 Est. | 5.5 | 24 | 4.0 |
| | | | T | 30 | 28 Est. | 5.6 | 21 | 5.3 |
| | | B No needles | B | 15 | 28 Est. | 6.4 | 29 | 4.1 |
| | | | T | 15 | 28 Est. | 6.1 | 19 | 4.5 |
| | | C Deep checks, weathering, No.: twigs, small branches | B | 14 | 28 Est. | 6.0 | 22 | 4.5 |
| | | | T | 21 | 28 Est. | 6.0 | 22 | 5.4 |
| | Live | L Living trees | B | 65 | 28 Est. | 5.4 | 24 | 7.0 |
| | | | T | 93 | 28 Est. | 6.1 | 23 | 4.8 |
| Lodgepole Pine | Standing Dead | A As above | B | 24 | 28 Est. | 6.3 | 21 | 5.7 |
| | | | T | 15 | 28 Est. | 7.8 | 18 | 5.9 |
| | | B As above | B | 14 | 28 Est. | 7.0 | 20 | 2.9 |
| | | | T | 15 | 28 Est. | 7.9 | 26 | 5.4 |
| | | C As above | B | 17 | 28 Est. | 7.9 | 22 | 5.0 |
| | | | T | 15 | 28 Est. | 8.2 | 21 | 6.3 |
| | Down | D Same as C but not standing | B | 24 | 28 Est. | 6.7 | 23 | 5.8 |
| | | | T | 25 | 28 Est. | 7.1 | 19 | 4.0 |
| | Live | E Living trees | B | 80 | 28 Est. | 5.5 | 29 | 6.7 |
| | | | T | 94 | 28 Est. | 5.9 | 27 | 6.2 |
| Means | | White Pine | | | | 5.9 | 23 | 4.9 |
| | | Lodgepole Pine | | | | 6.2 | 23 | 5.4 |
| | | Both | | | | 6.0 | 23 | 5.2 |

Table 4. Characteristics of Flakes Prepared by Ring Flaker.

| Species | | Deterioration Class | Top or Bole | Moisture Content of Chips % | Energy kWh/ODT | Bulk Density lb/cu ft | Slenderness Ratio L/T | Fines % (-42% Tyler) |
|---|---|---|---|---|---|---|---|---|
| White Pine | Standing Dead | A Red needles, bark mostly intact | B | 35 | 28 Est. | 5.5 | 24 | 4.0 |
| | | | T | 30 | 28 Est. | 5.6 | 21 | 5.3 |
| | | B No needles | B | 15 | 28 Est. | 6.4 | 29 | 4.1 |
| | | | T | 15 | 28 Est. | 6.1 | 19 | 4.5 |
| | | C Deep checks, weathering, No.: twigs, small branches | B | 14 | 28 Est. | 6.0 | 22 | 4.5 |
| | | | T | 21 | 28 Est. | 6.0 | 22 | 5.4 |
| | Live | L Living trees | B | 65 | 28 Est. | 5.4 | 24 | 7.0 |
| | | | T | 93 | 28 Est. | 6.1 | 23 | 4.8 |
| Lodgepole Pine | Standing Dead | A As above | B | 24 | 28 Est. | 6.3 | 21 | 5.7 |
| | | | T | 15 | 28 Est. | 7.8 | 18 | 5.9 |
| | | B As above | B | 14 | 28 Est. | 7.0 | 20 | 2.9 |
| | | | T | 15 | 28 Est. | 7.9 | 26 | 5.4 |
| | | C As above | B | 17 | 28 Est. | 7.9 | 22 | 5.0 |
| | | | T | 15 | 28 Est. | 8.2 | 21 | 6.3 |
| | Down | D Same as C but not standing | B | 24 | 28 Est. | 6.7 | 23 | 5.8 |
| | | | T | 25 | 28 Est. | 7.1 | 19 | 4.0 |
| | Live | E Living trees | B | 80 | 28 Est. | 5.5 | 29 | 6.7 |
| | | | T | 94 | 28 Est. | 5.9 | 27 | 6.2 |
| Means | | White Pine | | | | 5.9 | 23 | 4.9 |
| | | Lodgepole Pine | | | | 6.2 | 23 | 5.4 |
| | | Both | | | | 6.0 | 23 | 5.2 |

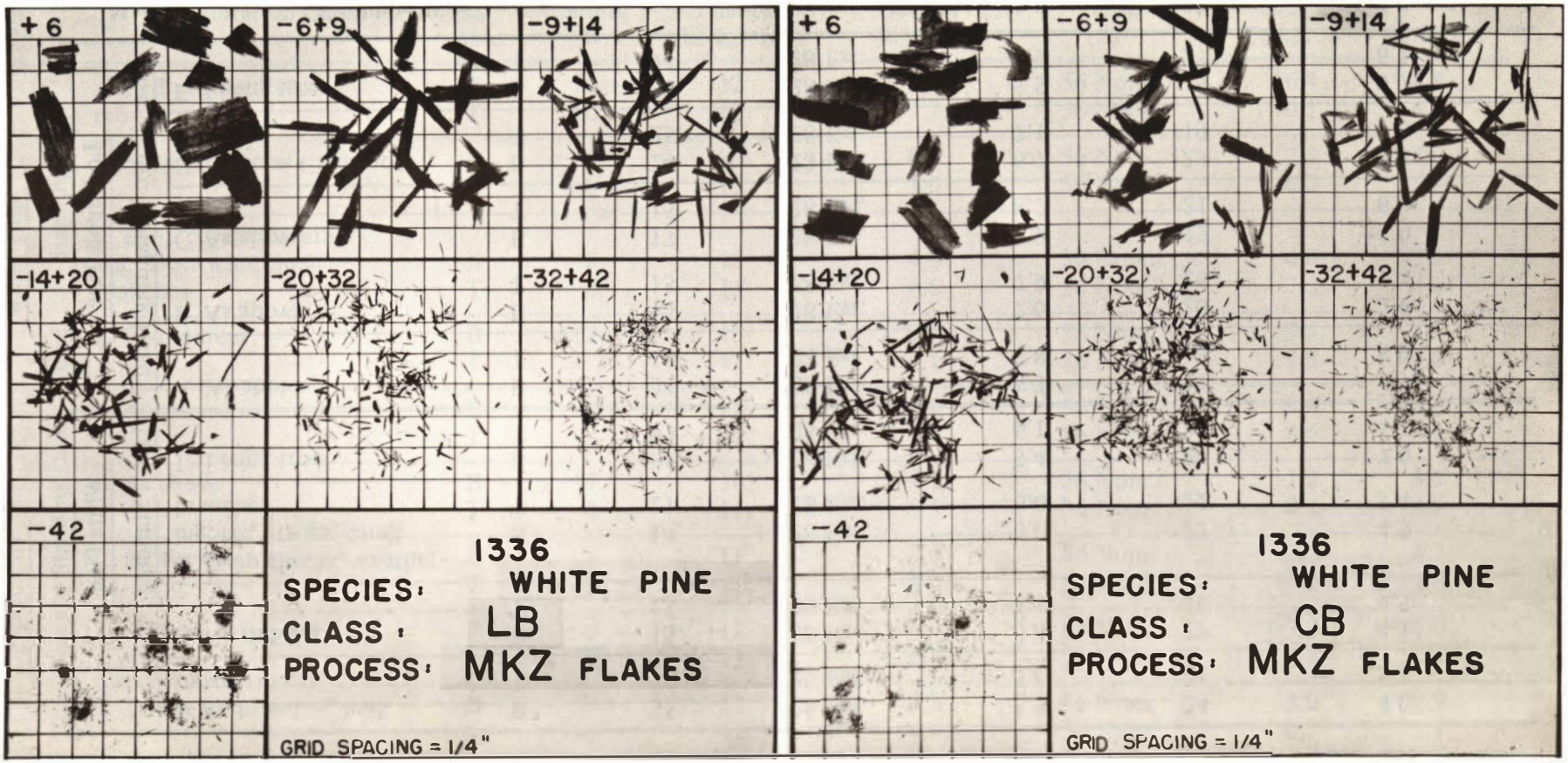



Figure 8. Comparison of Typical Ring-Flaked Particles from Live Trees (Class L) and Dead Trees (Class C).

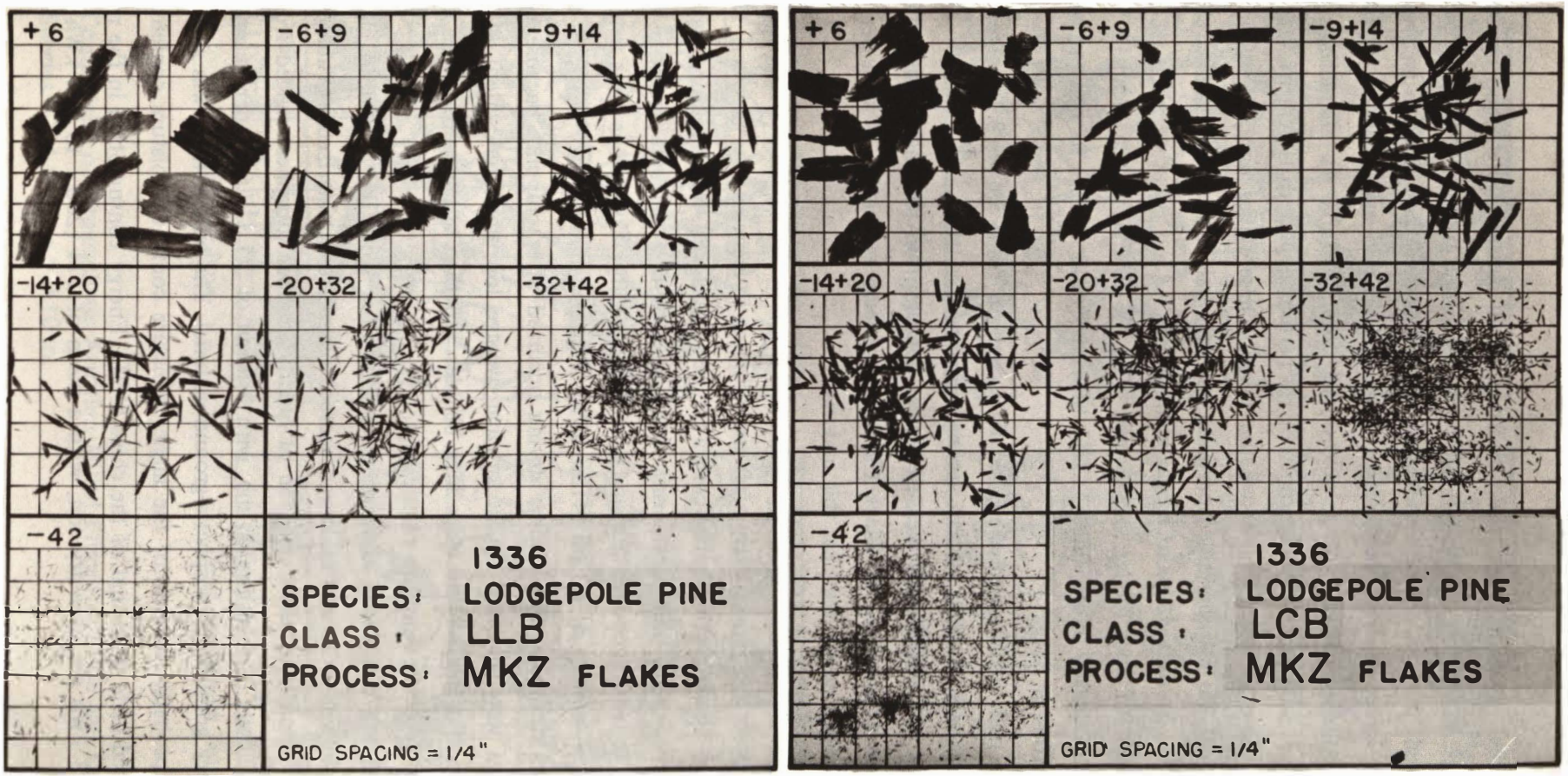



Figure 9. Comparison of Typical Ring-Flaked Particles from Live Trees (Class L) and Dead Trees (Class C).

Tyler screen analyses were made of flakes of all classes. Length and thickness measurements were made of samples from each screen fraction and average length/thickness ratios were computed for each fraction. These slenderness ratios then were combined in an average weighted according to the screen fraction percentages to give a weighted mean slenderness ratio characterizing the corresponding material class (next-to-last column, Table 4). Slenderness ratios ranged from 18.6 to 29.3, with a grand mean of 22.8. No particular pattern is evident, although the live lodgepole (28.1) was substantially above the mean. These flakes have about three times the slenderness ratio of the hammermilled particles but only half that of the drum-cut flakes. Higher ratios could be had by using chips of longer grain length.

The amount of fines (Tyler -42) ranged from 4% to 7%, with a mean of 5.2%. The live material produced slightly more fines (6.2%) than the dead (4.9%) in contrast to the reverse situation with drum-cut flakes.

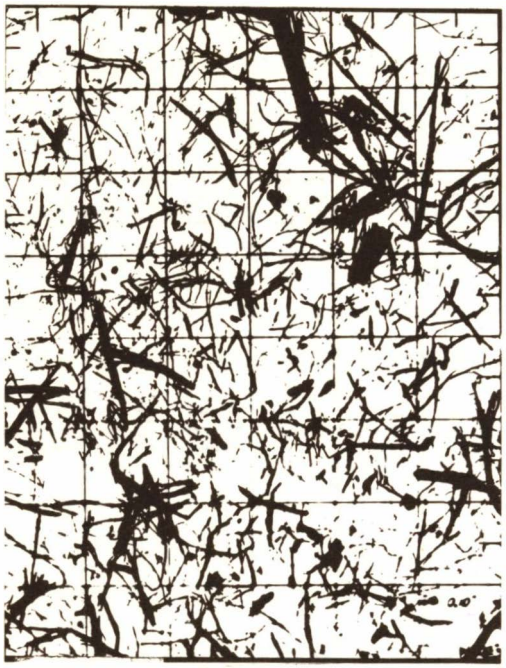
Measured bulk densities of the dried flakes ranged from 5.4 to 8.2 lbs per cu ft (87 to 131 kg per cu m), with no clear pattern among the classes.

No means was available to measure power consumption for flaking the different classes. Based on previous experience, the Black Clawson engineers estimated 28 kWh per oven-dry ton (31 kWh per oven-dry metric ton) for this material.

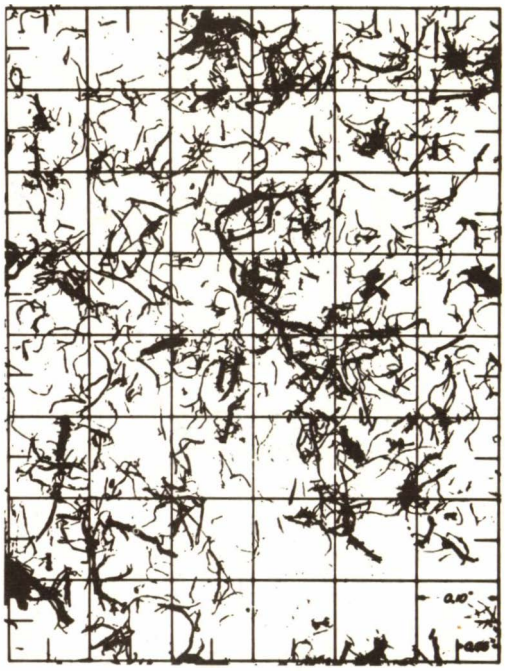
Atmospheric Attrition Milling: Chips from each material class were milled in an atmospheric attrition mill immediately after pre-steaming in a pressurized digester. The mill was a 24-in. (610 mm) Bauer with double contra-rotating disks and was equipped with Bauer No. 24301/302 plates. Several preliminary runs were made to find the best operating conditions to make a fine fiber with good length and low bulk density. Conditions thus established were pre-steaming for 5 minutes at 60 psi (413.6 kPa), 5 lbs-per-minute (2.27 kg) feed, and 0.040 in. (1.02 mm) plate clearance. Since some drying occurred after chipping because of a delay in refining, all chips were adjusted to the original average log moisture content by spraying the required amount of water on the chips in a blender and then allowing the chips to equilibrate for three days while being stored in plastic bags.

A photograph comparing atmospheric-refined fiber from live and dead classes of both species is shown in Figure 10 and measured characteristics are summarized in Table 5.

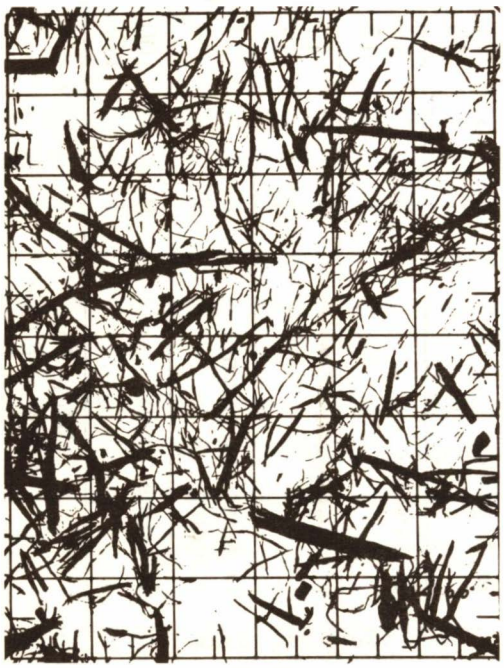
Dry bulk density (a usual criterion of quality in fiber furnishes) ranged from 0.8 to 1.4 lbs per cu ft (12.8 to 22.4 kg per cu m), with a mean of 1.1 (17.6 kg per cu m). This can be considered as very good for atmospheric-ground material. The bulk density was slightly lower for the live classes, probably because of the higher moisture content. Moisture content of the fiber (40%) was changed little from that of the chips (48%). Energy consumption in the milling ranged from 146 to 203 kWh per oven-dry ton, with a mean of 174 (260.1 to 224 kWh per oven-dry



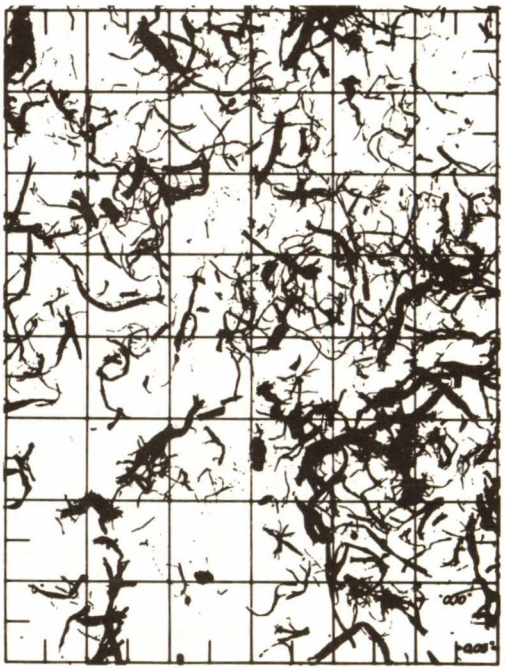
Live White Pine



Dead White Pine



Live Lodgepole Pine



Dead Lodgepole Pine

Figure 10. Comparison of Atmospheric Attrition Milled Fiber from Live and Dead Trees of Both Species. Grid Spacing = 0.10 in.

Table 5. Characteristics of Fiber Prepared by Atmospheric Attrition Mill.

| Species | | Deterioration Class | Top or Bole | Moisture Content of Chips % | Moisture Content of Fiber % | Energy kWh/ODT | Bulk Density lb/cu ft |
|---|---|---|---|---|---|---|---|
| White Pine | Standing Dead | A Red needles, bark mostly intact | B | 37 | 48 | 203 | 0.91 |
| | | | T | 32 | 21 | 164 | 1.21 |
| | | B No needles | B | 20 | 16 | 189 | 1.00 |
| | | | T | 20 | 20 | 183 | 1.12 |
| | | C Deep checks, weathering. No: twigs, small branches | B | 17 | 17 | 199 | 1.21 |
| | | | T | 14 | 20 | 179 | 1.20 |
| | Live | L Living trees | B | 89 | 94 | 176 | 0.87 |
| | | | T | 96 | 92 | 140 | 0.80 |
| Lodgepole Pine | Standing Dead | A As above | B | 21 | 43 | 200 | 0.87 |
| | | | T | 20 | 17 | 183 | 0.97 |
| | | B As above | B | 14 | 21 | 181 | 1.07 |
| | | | T | 13 | 14 | 158 | 1.17 |
| | | C As above | B | 11 | 13 | 159 | 1.43 |
| | | | T | 13 | 19 | 154 | 1.44 |
| | Down | D Same as C but not standing | B | 24 | 21 | 177 | 1.30 |
| | | | T | 23 | 21 | 184 | 1.42 |
| | Live | L Living trees | B | 100 | 96 | 160 | 0.99 |
| | | | T | 121 | 123 | 146 | 1.11 |
| Means | | White Pine | | | | 179 | 1.04 |
| | | Lodgepole Pine | | | | 170 | 1.17 |
| | | Both | | | | 174.5 | 1.10 |

metric ton, with a mean of 192). To this would have to be added 7 kWh per oven-dry ton (7.7 kWh per oven-dry metric ton) for chipping and an unmeasured amount of energy for steaming the chips. The only relationship apparent among classes was slightly higher power use for the boles than for the tops.

Pressurized Attrition Milling: Pressurized refining uses a combination of a continuous steam digester and an attrition mill with a pressurized casing, arranged so that the steamed chips are continuously moved from the digester into the mill without being depressurized. The milled fiber furnish expands to atmospheric pressure as it is blown continuously from an orifice in the perimeter of the mill casing.

Chips of all classes were pressure-refined in the laboratory of CE Bauer in Springfield, Ohio.

Chips from each class were milled in a Model 418 Bauer pressurized refiner using 36325/326 plates. Operating conditions were:

| | |
|---|---|
| Steam pressure | 85 psi (586 kPa) |
| Dwell time | 5 minutes |
| Plate setting | 0.015 in. (0.38 mm) |
| Feed rate | 6 to 8 lbs/min (2.73 to 3.64 kg/min) |

Fiber characteristics are summarized in Table 6, and a photograph comparing fibers from live and dead classes of both species is shown in Figure 11. Bulk density ranged from 0.77 to 1.11 lbs per cu ft (12.3 to 17.8 kg per cu m) with a mean of 1.0 lb per cu ft (16 kg per cu m). These values were almost identical to those of the atmospheric-refined fiber.

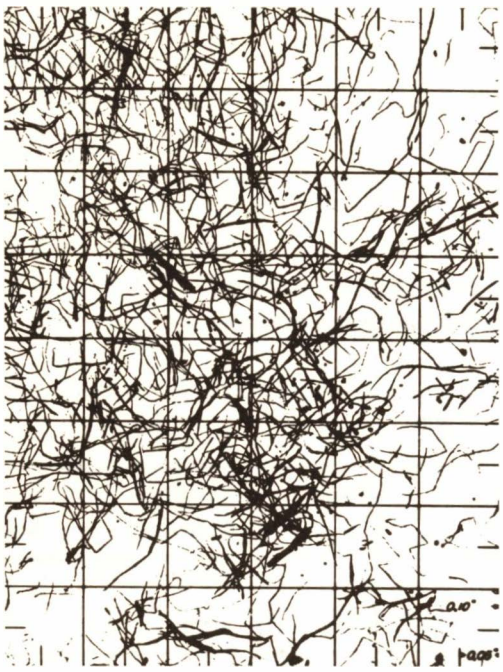
Power consumption ranged from 340 to 630 kWh/oven-dry ton (375 to 694 kWh/oven-dry metric ton), with a mean of 516 (569). It appeared that more energy was required when grinding higher moisture content chips. White pine required more energy (555 kWh) than did lodgepole pine (443 kWh). Total energy for fiber preparation also would include the estimated 7 kWh per oven-dry ton for chipping and an estimated 400 to 500 kWh per oven-dry ton (441 to 551 kWh per oven-dry metric ton) equivalent of energy in processing steam.

## Comparison of Particle-Preparation Methods

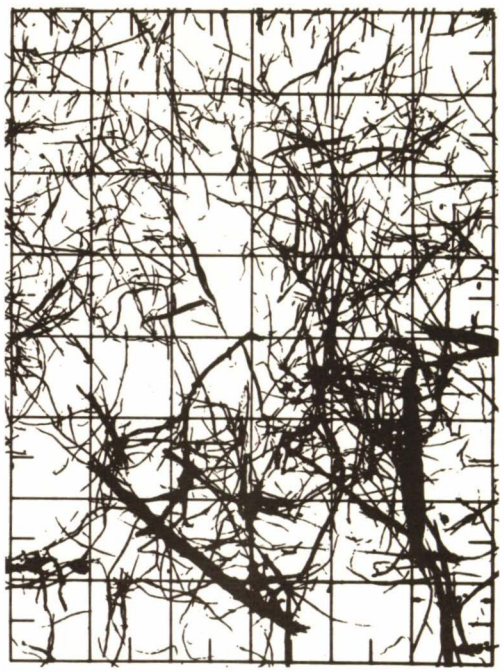
Table 7 summarizes the comparison of characteristics of the five particle types. The figures shown are grand means for all classes.

Table 6. Characteristics of Fiber Prepared by Pressurized Attrition Mill.

| Species | | Deterioration Class | Top or Bole | Moisture Content of Chips % | Moisture Content of Fiber % | Energy kWh/ODT | Bulk Density lb/cu ft |
|---|---|---|---|---|---|---|---|
| White Pine | Standing Dead | A Red needles, bark mostly intact | B | 30 | 21 | 630 | 1.03 |
| | | | T | 23 | 25 | 540 | 0.89 |
| | | B No needles | B | 10 | 11 | 550 | 1.20 |
| | | | T | 9 | 12 | 510 | 0.85 |
| | | C Deep checks, weathering. No: twigs, small branches | B | 10 | 23 | 490 | 0.92 |
| | | | T | 10 | 43 | 500 | 0.93 |
| | Live | L Living trees | B | 61 | 125 | 570 | 0.86 |
| | | | T | 96 | 98 | 650 | 0.76 |
| Lodgepole Pine | Standing Dead | A As above | B | 24 | 37 | 580 | 0.90 |
| | | | T | 17 | 10 | 420 | 1.01 |
| | | B As above | B | 11 | 14 | 450 | 0.89 |
| | | | T | 10 | 13 | 340 | 0.90 |
| | | C As above | B | 10 | 18 | 460 | 0.99 |
| | | | T | 10 | 11 | 420 | 1.01 |
| | Down | D Same as C but not standing | B | 10 | 18 | 450 | 1.03 |
| | | | T | 11 | 14 | 480 | 1.11 |
| | Live | L Living trees | B | 81 | 60 | 620 | 0.93 |
| | | | T | 99 | 121 | 620 | 0.98 |
| Means | | White Pine | | | | 555 | 0.93 |
| | | Lodgepole Pine | | | | 485 | 0.97 |
| | | Both | | | | 520 | 0.95 |

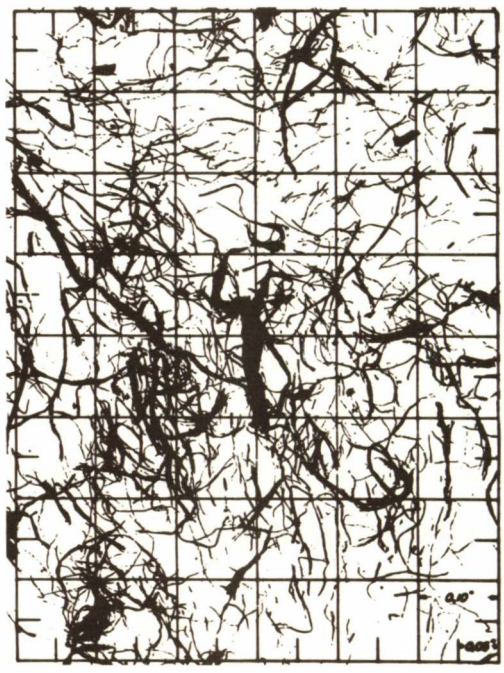


Live White Pine



Dead White Pine

Live Lodgepole Pine



Dead Lodgepole Pine

Figure 11. Comparison of Pressurized Attrition Milled Fiber from Live and Dead Trees of Both Species. Grid Spacing = 0.10 in.

Table 7. Comparison of Particle Types (Averaged for Both Species and All Deterioration Classes).

| | | Particle | Flake | | Fiber | |
|---|---|---|---|---|---|---|
| | | Hammer-mill | Ring-Flaker | Drum-Flaker | Atoms.-Attrition | Pressure-Attrition |
| Particle Geometry | % Fines -42 | 4.1 | 5.2 | 4.6 | --- | --- |
| | L/T Ave | 8.4 | 22.8 | 50 Nom. | --- | --- |
| Power (kWh/ODT) | | 69 | 35 | 12 | 181 + Steam | 523 + Steam |
| Bulk Density (lb/cu ft) | | 10.7 | 6.5 | 5.0 | 1.1 | 1.0 |
| Closing Pressure psi | *$\rho$ = 0.65 | 390 | | 370 | | 360 |
| | $\rho$ = 0.85 | 720 | | 710 | | 500 |
| IB, psi Phenolic | $\rho$ = 0.65 | 119 | | 55 | | 64 |
| | $\rho$ = 0.85 | 204 | | 93 | | 120 |
| IB, psi Urea | $\rho$ = 0.65 | 168 | | 78 | | 97 |
| | $\rho$ = 0.85 | 245 | | 122 | | 140 |
| IB Mean | | 184 | --- | 87 | --- | 105 |

*$\rho$ is nominal board specific gravity.

The amount of fines generated was about the same (4% to 5%) for hammermilling and both types of flaking; screen analysis was not practical for the fiber types.

The slenderness ratio of the drum-flaked particles (50 nominal) was twice that of the ring-flaked particles (22.8), which in turn was two and one half times that of the hammermilled particles (8.4). The slenderness ratio of the fiber was not measured but probably would be as great as that of the drum flakes. Increasing slenderness tends to enhance bending strength and stiffness but tends to decrease internal bond strength.

The energy requirements for the different processes cover a very wide range. In order of increasing energy requirement in kWh per oven-dry ton (metric ton), they were:

| | |
|---|---|
| Drum flaking | 12 (13.2) |
| Ring flaking | 35 (38.6) |
| Hammermilling | 69 (76.1) |
| Atmospheric-attrition milling | 101 (111) (plus processing steam) |
| Pressurized-attrition milling | 523 (577) (plus 450 kWh [496] in processing steam) |

Only in the hammermilling and the pressure-refining were the energy requirements increased substantially by an increase in moisture content.

Bulk density of the furnishes is an important parameter in determining the sizes and requirements of plant equipment for handling, storing, blending, mat-forming, prepressing, and pressing. The hammermilled material was the most compact, at 10.7 lbs per cu ft (171 kg per cu m). The flakes were intermediate, at 6.5 lbs (104 kg) for the ring flakes and 5 lbs (90 kg) for the drum flakes. The two fiber furnishes were much bulkier and were almost identical, at about 1 lb per cu ft (16 kg per cu m).

For the three furnishes used to prepare boards, the required press closing pressure was about the same at the lower board density level; but, at the higher density, the pressure-refined fiber afforded substantially lower closing pressure (500 psi–3.45 MPa) than did the drum flakes (710 psi–4.89 MPa) or the hammermilled particles (720 psi–4.96 MPa).

## Compatibility with Commercial Resins

Practically all of the commercial dry-process composition board production in the United States uses either urea-formaldehyde or phenol-formaldehyde resin adhesives–with the urea resins constitutingabout 90% of the total. Thus, compatibility with these two resin types would be of

most importance to users of this potential resource for composition board production.

Urea-formaldehyde board resins are acid-curing and require either wood of sufficient acidity or else the addition of acid catalysts to the resin. The amount of the additive depends not only on the acidity of the wood as measured on the pH scale but also on the degree of buffering of the wood. Thus, pH and buffering and their variability among the classes of material are important criteria of resin compatibility.

IB strength, the tensile strength perpendicular to the surface, of composition board is usually more sensitive to the quality of resin bonding than are other strength properties. Thus, production of composition board from all of the classes of material, using both urea and phenolic resins and measurement of IB strength, was included in the first phase plan as a further criterion of resin compatibility. It was thought that this would detect any marked lack of specific adhesion due to age, weathering, sapstain, or decay.

## Acidity and Buffering

A recognized method of measuring the acidity and degree of buffering of wood furnish was used in this study (2).

The results (Table 8) show a narrow range of pH, from 4.07 to 4.59, with means of 4.40 for white pine and 4.33 for lodgepole. Buffering capacity ranged from 0.058 to 0.165 milli-equivalents, with means of 0.090 for white pine and 0.124 for lodgepole. The buffering capacity was determined by titration of 150 ml of the leachate used for the pH measurement with 0.01 N sulfuric acid to a 3.5 pH end point. The pH level was low enough to require no separate catalyst in a urea resin system, and the range was sufficiently narrow so that varying mixtures of classes of material should cause no difficulty with resin formulation.

## Internal Bond Strength

Composition boards were prepared as outlined under "Experimental Plan" above, using a factorial design involving the 18 material classes, three particle types (hammermilled, pressure-refined fiber, and drum-cut flakes), two resin types (phenolic and urea), two board densities (0.65 and 0.85 specific gravity), and two replications of each batch. An additional block of 32 boards was made from the live class, drum-cut flakes after passing the flakes through a hammermill without a screen to split the extra-wide flakes to narrower widths. Randomization of the order in which the batches were produced was practical only within each of six blocks, each block using one resin type and one particle type. Strictly, then, such statistical techniques

Table 8. Acidity and Buffering Capacity.

| Species | | Deterioration Class | Top or Bole | Acidity pH | Buffering (meq. of $H_2SO_4$) |
|---|---|---|---|---|---|
| White Pine | Standing Dead | A Red needles, bark mostly intact | B | 4.35 | 0.087 |
| | | | T | 4.50 | 0.121 |
| | | B No needles | B | 4.51 | 0.089 |
| | | | T | 4.50 | 0.088 |
| | | C Deep checks, weathering. No: twigs, small branches | B | 4.30 | 0.088 |
| | | | T | 4.53 | 0.112 |
| | Live | L Living trees | B | 4.07 | 0.063 |
| | | | T | 4.47 | 0.150 |
| Lodgepole Pine | Standing Dead | A As above | B | 4.47 | 0.110 |
| | | | T | 4.59 | 0.158 |
| | | B As above | B | 4.43 | 0.123 |
| | | | T | 4.55 | 0.165 |
| | | C As above | B | 4.20 | 0.110 |
| | | | T | 4.33 | 0.122 |
| | Down | D Same as C but not Standing | B | 4.08 | 0.076 |
| | | | T | 4.25 | 0.117 |
| | Live | L Living trees | B | 4.22 | 0.118 |
| | | | T | 4.22 | 0.143 |
| Means | | White Pine | | 4.40 | 0.090 |
| | | Lodgepole Pine | | 4.33 | 0.124 |
| | | Both | | 4.36 | 0.107 |

as analysis of variance can be applied only to the data of each block separately.

Board-making details are summarized in Table 9. Several preliminary boards were made in each of the six blocks (resin type by particle type) to establish blending, forming, and pressing conditions which would assure well-blended, well-cured boards of reasonably uniform density. Resins used were commercial composition-board resins appropriate to the particle types. The board formulation and manufacturing details are not presented as being optimum practice for commercial utilization of this resource.

The boards, after appropriate conditioning, were tested in IB according to American Society for Testing and Materials procedure D 1037, "Standard Methods of Evaluating the Properties of Wood-Base Fiber and Particle Panel Materials." Four tests were made on each board. The four test values for each board gave 16 values per treatment (four tests per board by two board specific gravities by two replicate batches) which were subjected to linear regression analysis of IB on density to afford predicted means of IB strength at the two nominal densities. Correlation coefficients were mostly above 0.9. These predicted means for the two density levels (0.65 and 0.85) are shown in Tables 10 and 11. The data are graphed in Figures 12 to 14.

Analysis of the IB data reveals a complex situation, in which the IB strengths associated with the different material classes are ranked differently for different particle types and resin types.

If we consider first the differences between tops and boles, we find only moderate differences, mostly favoring tops. For the entire experiment the average IB for tops is 132 psi (0.91 MPa), while that for boles is 122 psi (0.84 MPa). To simplify, let us combine tops and boles and confine our discussion for the moment to predicted IB values at 0.65 specific gravity. If we further combine all the dead classes for each species into a single dead class to compare with the corresponding live or "control" class, we have the simplified table on the next page.

Consider first the boards from hammermilled particles. In these boards, lodgepole affords higher IB than does white pine, while 7% urea resin, as expected, affords higher IB than does 4% phenolic resin. With phenolic resin the dead classes in both white pine and lodgepole give higher IB than the live classes, while with urea resin the live classes are slightly higher in both species. Thus, on the basis of IB, there is no unambiguous superiority of either the live or dead material, although averaged over all the hammermilled material the dead classes at 141 psi (0.97 MPa) are a little above the live classes at 134 psi (0.92 MPa). It seems logical to ascribe this to differences in particle geometry caused by milling the dead material at lower moisture content.

Next consider the boards from pressure-refined fiber. Here the difference in resin level is not proportionately as great (7% phenolic vs 9% urea). This is reflected in the more moderate corresponding IB superiority of the urea over the phenolic boards. The species difference, however, is reversed in relation to the hammermilled boards, with white pine now giving slightly

Table 9. Summary of Board-Making Details.

| Particle Type | | | Hammermilled | | Pressure-refined Fiber | | Drum-cut Flakes | |
|---|---|---|---|---|---|---|---|---|
| Resin Type | | | Phenolic | Urea | Phenolic | Urea | Phenolic | Urea |
| Furnish Fractions Removed | | | -42 removed | | Nothing removed | | Heavy particles and dust removed | |
| Additives | Resin | Maker | Borden | Pacific Resins | Borden | Borden | Borden | Pacific Resins |
| | | Number | MB 43 (193-32) | S3109C | MH193-32 | WC210101 | MB 43 (193-32) | S3109C |
| | | Amt Used % solids | 4 | 7 | 7 | 9 | 4 | 7 |
| | % wax (EW 407 mixed with resin) | | 0.75 | 0.75 | 0.75 | 0.75 | 0.75 | 0.75 |
| Blending (Rotary-drum blender) | Pretreatment | | None | | Fluffed | | None | |
| | Spraying (air atomizing) | Pressure psi(kPa) | 40(276) | 40(276) | 40(276) | 40(276) | 40(276) | 40(276) |
| | | Time min. | 6 | 4-5 | 4-5 | 3-4 | 6 | 3-4 |
| | | Temp °F(C) | 95(35) | 80(27) | 95(35) | 80(27) | 95(35) | 80(27) |
| | | Dilution % Act. Solid. | 42 | 66 | 42 | 55 | 42 | 66 |
| | | Viscosity Centi-stokes | | 225 | | 165 | | 225 |
| | After Treatment | | None | | Bauer milled at 0.1 in. (2.5mm) clearance | | None | |
| | Mat Forming | | Hand-fed, vibrating-string former | | Vacuum-formed, vibrating-string former | | By hand in deckle box | |
| Prepressing | Pressed to: | | 350 psi (2.41 MPa) | | 2 in. (50mm) thick in deckle box | | 350 psi (2.41 MPa) | |
| | Mat Thickness | Before | 2 to 3 in. (25 to 75 mm) | | 12 in. + (300 mm) | | 2.5 to 3.5 in. (63 to 88 mm) | |
| | | After | 1 to 1 1/4 in. (25 to 32 mm) | | 4 to 5 in. (100 to 125 mm) | | 1 to 2 in. (25 to 50 mm) | |
| Hot Pressing | Mat MC percent | | 7-9 | 7.5-9 | 10-11 | 10-12 | 7-8 | 7-8 |
| | Press Temp °F(C) | | 375(191) | 325(163) | 400(204) | 325(163) | 375(191) | 325(163) |
| | Time to stops, sec. | | 60 | 60 | 45 | 45 | 60 | 60 |
| | Press Time | High $\rho$ | 6 min. | 4 min. | 7 min. | 4 min. | 6 min. | 5 min. |
| | | Low $\rho$ | 5 min. | 4 min. | 6 min. | 4 min. | 5 min. | 5 min. |

Table 10. Internal Bond Strength [psi (MPa)] Adjusted to 0.65 Specific Gravity.

| Species | | Deterioration Class | Top or Bole | Hammermilled Particles | | Pressure-Refined Fiber | | Drum-Cut Flakes | | Milled Drum-Cut Flakes | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Phenolic | Urea | Phenolic | Urea | Phenolic | Urea | Phenolic | Urea |
| White Pine | Standing Dead | A Red needles, bark mostly intact | B | 92 (0.63) | 139 (0.96) | 75 (0.52) | 113 (0.78) | 44 (0.30) | 76 (0.52) | | |
| | | | T | 104 (0.72) | 162 (1.12) | 79 (0.55) | 121 (0.83) | 50 (0.35) | 66 (0.46) | | |
| | | B No needles | B | 105 (0.72) | 147 (1.01) | 74 (0.51) | 109 (0.75) | 33 (0.23) | 63 (0.43) | | |
| | | | T | 99 (0.68) | 132 (0.91) | 76 (0.52) | 117 (0.81) | 43 (0.30) | 65 (0.45) | | |
| | | C Deep checks, weathering. No: twigs, small branches | B | 103 (0.71) | 117 (0.81) | 59 (0.41) | 104 (0.72) | 33 (0.23) | 50 (0.35) | | |
| | | | T | 83 (0.57) | 119 (0.82) | 83 (0.57) | 109 (0.75) | 40 (0.28) | 61 (0.42) | | |
| | Live | L Living trees | B | 75 (0.52) | 130 (0.90) | 65 (0.45) | 108 (0.75) | 20 (0.14) | 42 (0.29) | 77 (0.53) | 134 (0.92) |
| | | | T | 104 (0.72) | 159 (1.10) | 77 (0.53) | 98 (0.68) | 37 (0.26) | 51 (0.35) | 66(0.46) | 106 (0.73) |
| Lodgepole Pine | Standing Dead | A As above | B | 123 (0.85) | 168 (1.16) | 58 (0.40) | 81 (0.56) | 59 (0.41) | 81 (0.56) | | |
| | | | T | 130 (0.90) | 179 (1.23) | 63 (0.43) | 97 (0.67) | 50 (0.35) | 86 (0.59) | | |
| | | B As above | B | 149 (1.03) | 173 (1.19) | 75 (0.52) | 107 (0.74) | 55 (0.38) | 80 (0.55) | | |
| | | | T | 162 (1.12) | 196 (1.35) | 64 (0.44) | 86 (0.59) | 76 (0.52) | 93 (0.64) | | |
| | | C As above | B | 134 (0.92) | 207 (1.43) | 62 (0.43) | 83 (0.57) | 57 (0.39) | 91 (0.63) | | |
| | | | T | 146 (1.01) | 190 (1.31) | 64 (0.44) | 73 (0.50) | 98 (0.68) | 106 (0.73) | | |
| | Down | D Same as C but not standing | B | 134 (0.92) | 198 (1.37) | 50 (0.35) | 67 (0.46) | 70 (0.48) | 87 (0.60) | | |
| | | | T | 151 (1.04) | 216 (1.49) | 57 (0.39) | 69 (0.48) | 75 (0.52) | 107 (0.74) | | |
| | Live | L Living trees | B | 111 (0.77) | 195 (1.34) | 47 (0.32) | 82 (0.57) | 78 (0.54) | 86 (0.59) | 114 (0.79) | 166 (1.14) |
| | | | T | 115 (0.79) | 195 (1.34) | 85 (0.59) | 129 (0.89) | 73 (0.50) | 116 (0.80) | 110 (0.76) | 197 (1.36) |
| Means | | White pine | Dead | 97 (0.67) | 136 (0.94) | 74 (0.51) | 112 (0.77) | 40 (0.28) | 63 (0.43) | | |
| | | | Live | 89 (0.61) | 144 (0.99) | 71 (0.49) | 103 (0.71) | 28 (0.19) | 46 (0.32) | 71 (0.49) | 120 (0.83) |
| | | | Both | 93 (0.64) | 140 (0.97) | 72 (0.50) | 107 (0.74) | 34 (0.23) | 54 (0.37) | 71 (0.49) | 120 (0.83) |
| | | Lodgepole | Dead | 141 (0.97) | 191 (1.32) | 61 (0.42) | 83 (0.57) | 67 (0.46) | 91 (0.63) | | |
| | | | Live | 113 (0.78) | 195 (1.34) | 66 (0.46) | 105 (0.72) | 75 (0.52) | 101 (0.70) | 112 (0.77) | 181 (1.25) |
| | | | Both | 127 (0.88) | 193 (1.33) | 63 (0.43) | 94 (0.65) | 71 (0.49) | 96 (0.66) | 112 (0.77) | 181 (1.25) |

Table 11. Internal Bond Strength [psi (MPa)] Adjusted to 0.85 Specific Gravity.

| Species | | Deterioration Class | Top or Bole | Hammermilled Particles | | Pressure-Refined Fiber | | Drum-Cut Flakes | | Milled Drum-Cut Flakes | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Phenolic | Urea | Phenolic | Urea | Phenolic | Urea | Phenolic | Urea |
| White Pine | Standing Dead | A Red needles, bark mostly intact | B | 179 (1.23) | 218 (1.50) | 138 (0.95) | 170 (1.17) | 74 (0.51) | 126 (0.87) | | |
| | | | T | 202 (1.39) | 252 (1.74) | 115 (0.79) | 184 (1.27) | 92 (0.63) | 108 (0.74) | | |
| | | B No needles | B | 190 (1.31) | 231 (1.59) | 109 (0.75) | 162 (1.12) | 65 (0.45) | 91 (0.63) | | |
| | | | T | 169 (1.17) | 190 (1.31) | 144 (0.99) | 189 (1.30) | 78 (0.54) | 101 (0.70) | | |
| | | C Deep checks, weathering. No: twigs, small branches | B | 151 (1.04) | 172 (1.19) | 127 (0.88) | 149 (1.03) | 62 (0.43) | 80 (0.55) | | |
| | | | T | 149 (1.03) | 170 (1.17) | 124 (0.86) | 157 (1.08) | 70 (0.48) | 89 (0.61) | | |
| | Live | L Living trees | B | 146 (1.01) | 205 (1.41) | 122 (0.84) | 157 (1.08) | 47 (0.32) | 77 (0.53) | 157 (1.08) | 215 (1.48) |
| | | | T | 173 (1.19) | 225 (1.55) | 138 (0.95) | 156 (1.08) | 75 (0.52) | 97 (0.67) | 131 (0.90) | 173 (1.19) |
| Lodgepole Pine | Standing Dead | A As above | B | 218 (1.50) | 269 (1.86) | 112 (0.77) | 126 (0.87) | 106 (0.73) | 125 (0.86) | | |
| | | | T | 247 (1.70) | 279 (1.92) | 127 (0.88) | 166 (1.14) | 95 (0.66) | 136 (0.94) | | |
| | | B As above | B | 238 (1.64) | 273 (1.88) | 114 (0.79) | 146 (1.01) | 93 (0.64) | 129 (0.89) | | |
| | | | T | 245 (1.69) | 287 (1.98) | 97 (0.67) | 133 (0.92) | 124 (0.85) | 139 (0.96) | | |
| | | C As above | B | 236 (1.63) | 301 (1.08) | 131 (0.90) | 122 (0.84) | 92 (0.63) | 137 (0.95) | | |
| | | | T | 238 (1.64) | 288 (1.99) | 113 (0.78) | 122 (0.84) | 160 (1.10) | 175 (1.21) | | |
| | Down | D Same as C but not standing | B | 210 (1.45) | 272 (1.88) | 109 (0.75) | 103 (0.71) | 119 (0.82) | 131 (0.90) | | |
| | | | T | 240 (1.65) | 291 (2.01) | 111 (0.77) | 124 (0.86) | 128 (0.88) | 158 (1.09) | | |
| | Live | L Living trees | B | 205 (1.41) | 267 (1.84) | 88 (0.61) | 144 (0.99) | 138 (0.95) | 129 (0.89) | 189 (1.30) | 252 (1.74) |
| | | | T | 200 (1.38) | 254 (1.75) | 140 (0.97) | 188 (1.30) | 123 (0.85) | 172 (1.19) | 205 (1.41) | 266 (1.83) |
| Means | | White Pine | Dead | 173 (1.19) | 205 (1.41) | 126 (0.87) | 168 (1.16) | 73 (0.50) | 99 (0.68) | | |
| | | | Live | 159 (1.10) | 215 (1.48) | 130 (0.90) | 156 (1.08) | 61 (0.42) | 87 (0.60) | 144 (0.99) | 194 (1.34) |
| | | | Both | 170 (1.17) | 208 (1.43) | 127 (0.88) | 165 (1.14) | 70 (0.48) | 96 (0.66) | 144 (0.99) | 194 (1.34) |
| | | Lodgepole | Dead | 234 (1.61) | 282 (1.94) | 114 (0.79) | 130 (0.90) | 115 (0.79) | 141 (0.97) | | |
| | | | Live | 202 (1.39) | 260 (1.79) | 114 (0.79) | 166 (1.14) | 130 (0.90) | 150 (1.03) | 197 (1.36) | 259 (1.79) |
| | | | Both | 227 (1.57) | 278 (1.92) | 114 (0.79) | 137 (0.95) | 118 (0.81) | 143 (0.99) | 197 (1.36) | 259 (1.79) |

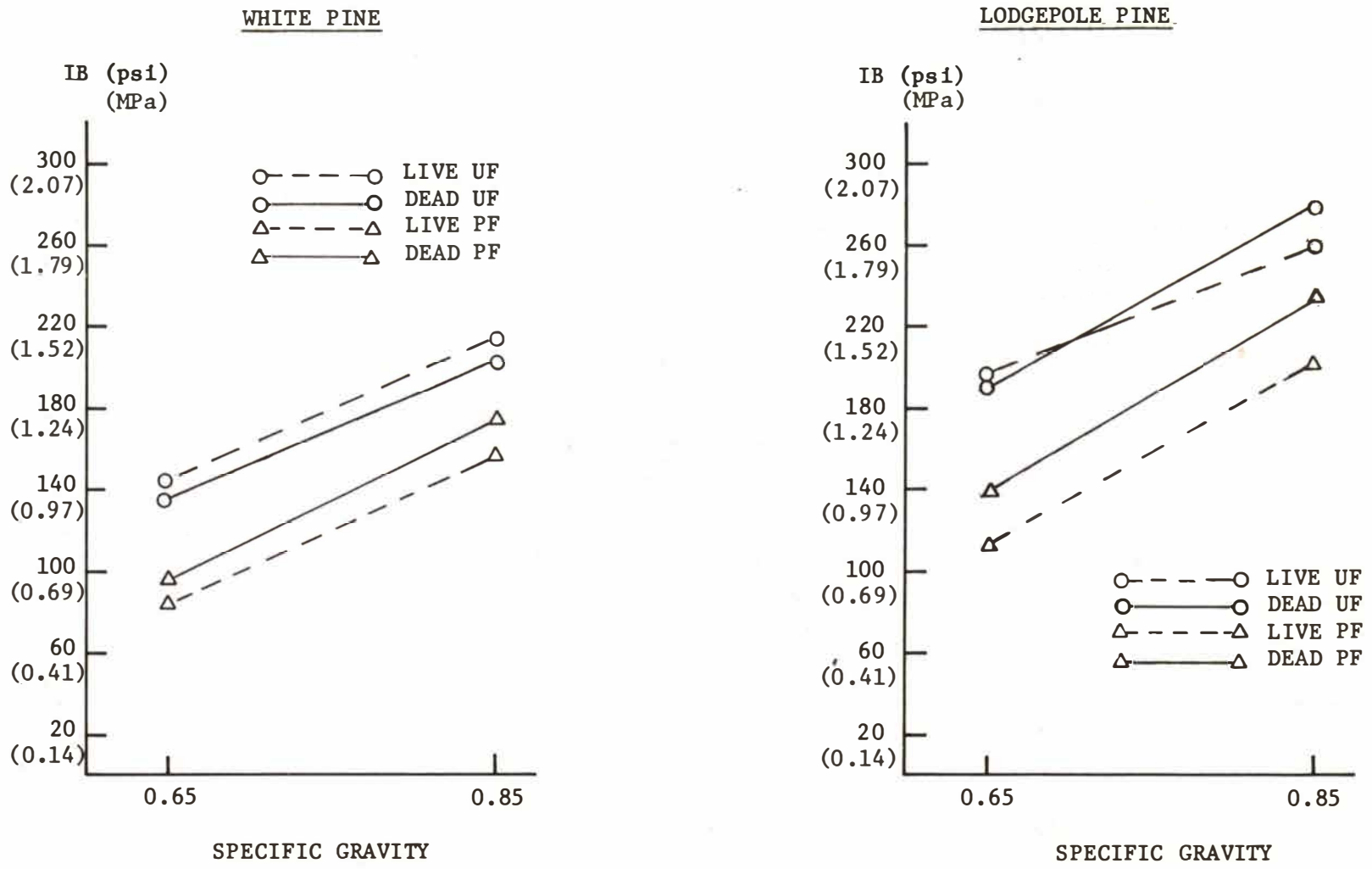



Figure 12. Specific Gravity vs. Internal Bond for Boards of Hammermilled Particles.

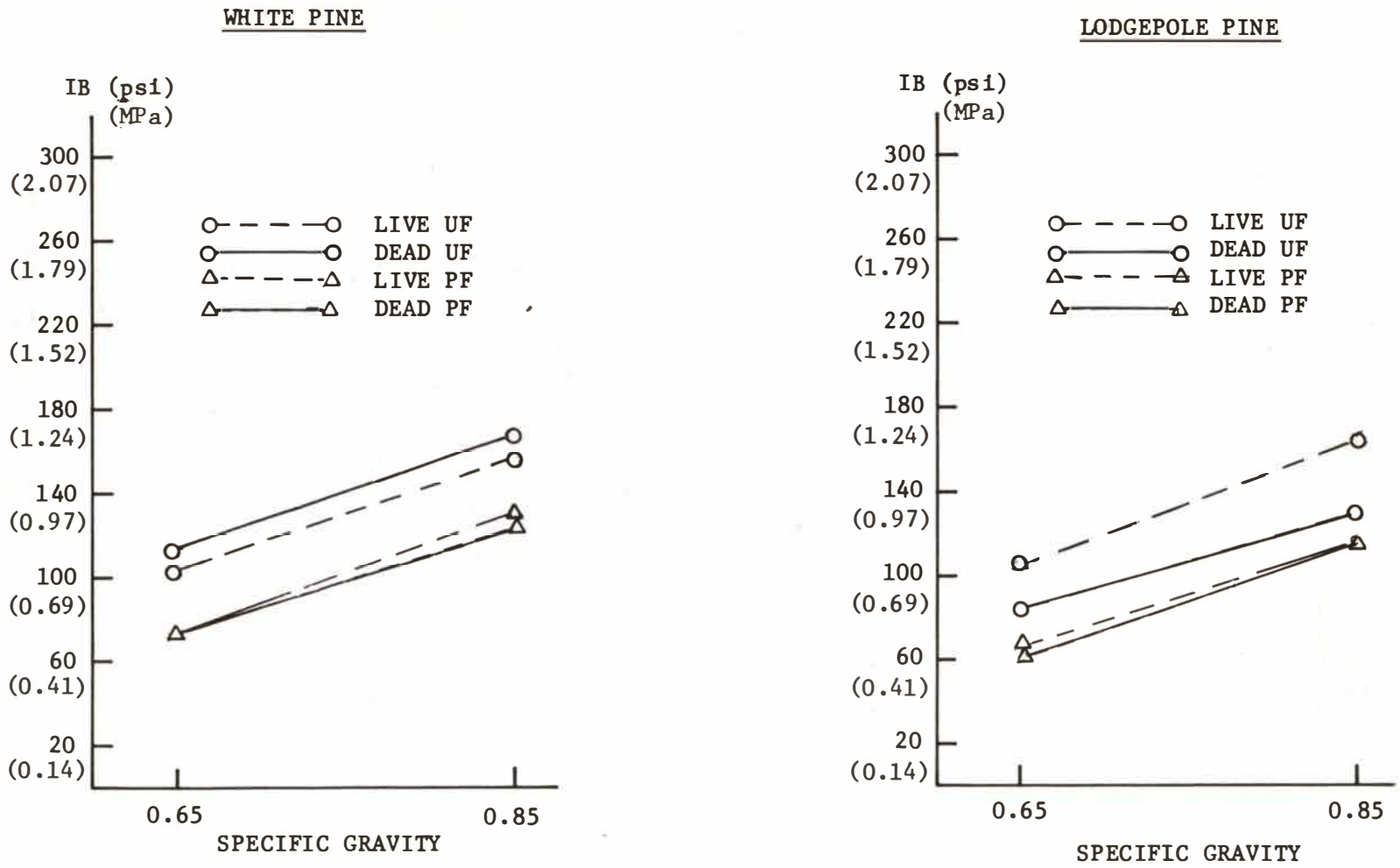



Figure 13. Specific Gravity vs. Internal Bond for Boards of Pressure-Refined Fiber.

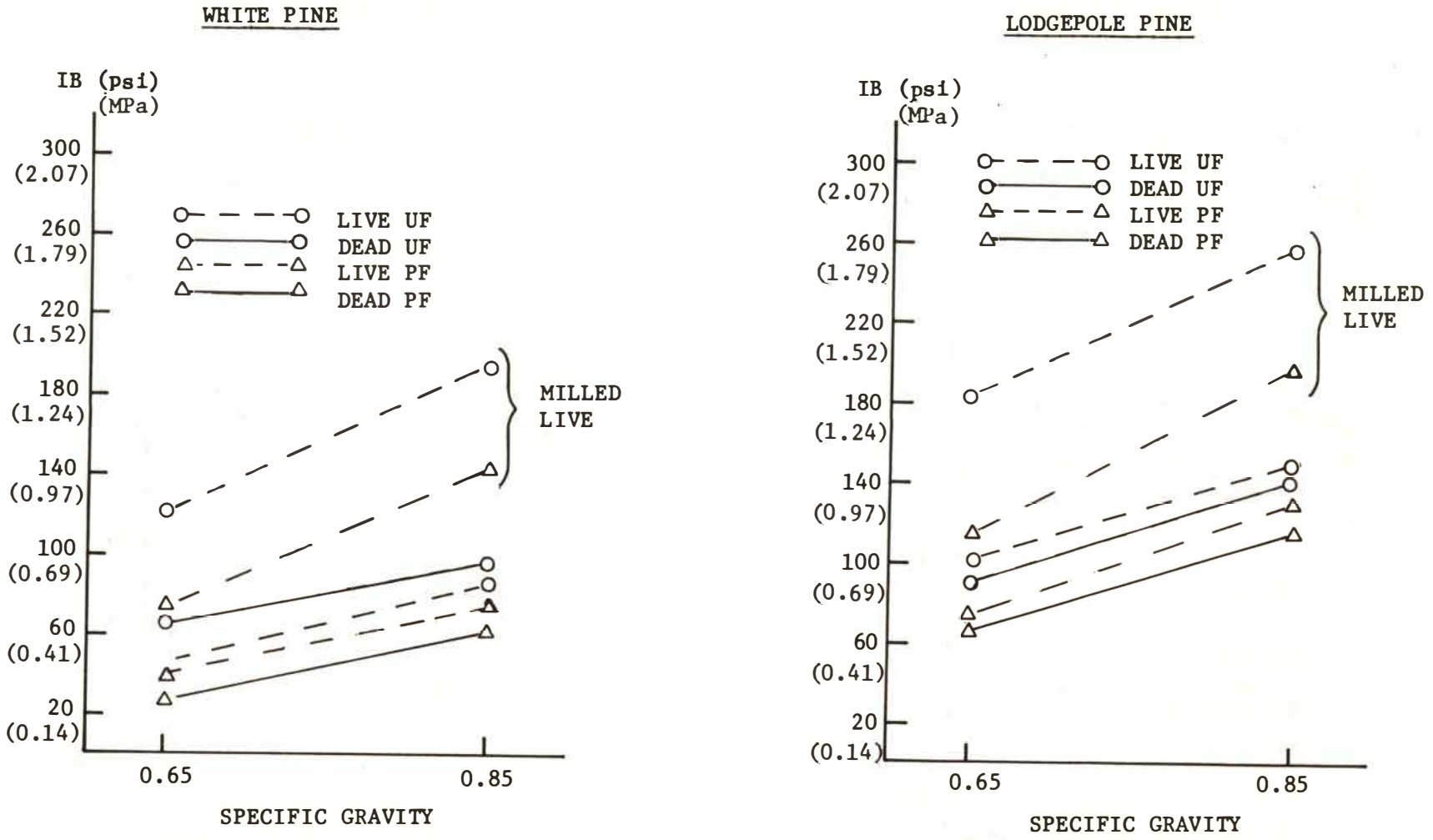



Figure 14. Specific Gravity vs. Internal Bond for Boards of Drum-Cut Flakes.

| Species | | Hammermilled Particles | | Pressure-Refined Fiber | | Drum-Cut Flakes | |
|---|---|---|---|---|---|---|---|
| | | PF(4%) | UF(7%) | PF(7%) | UF(9%) | PF(4%) | UF(7%) |
| White Pine | Live | 84 psi (0.58MPa) | 144 (0.99) | 71 (0.49) | 103 (0.11) | 71 (0.49) | 119 (Remilled) (0.82) |
| | | | | | | 29 (0.20) | 46 (Unmilled) (0.32) |
| | Dead | 98 (0.68) | 136 (0.94) | 74 (0.51) | 112 (0.77) | 41 (0.28) | 64 (0.44) |
| Lodgepole Pine | Live | 113 (0.78) | 195 (1.34) | 66 (0.46) | 105 (0.72) | 112 (0.77) | 181 (Remilled) (1.25) |
| | | | | | | 76 (0.52) | 101 (Unmilled) (0.70) |
| | Dead | 141 (0.97) | 191 (1.32) | 62 (0.43) | 83 (0.57) | 68 (0.47) | 91 (0.63) |

higher IB. With the fiberboards, the live classes have about the same IB as the dead classes: 86 psi (0.59 MPa) for the live and 83 psi (0.57 MPa) for the dead.

Considering lastly the boards from drum-cut flakes, we find the situation further complicated by the fact that boards were made from the live classes both with and without remilling of the flakes to split them to narrower widths. Here, as with hammermilled particles, lodgepole pine affords higher IB than does white pine; and 7% urea resin affords the expected IB superiority over 4% phenolic resin. With both species and both resin types, however, the IB for the dead classes falls between the IB for the unmilled and for the remilled flakes of the live classes, which are widely separated (the remilled flakes giving about twice the IB of the unmilled). Thus, with the drum-cut flakes, IB cannot be used as a criterion to evaluate any loss of resin compatibility in the dead classes because of the obvious confounding with the effects of moisture content on particle geometry.

If IB is to speak to the question of resin compatibility, it must be on the basis of the boards from hammermilled particles and from pressure-refined fiber. We feel that the internal bond strength comparisons between live and dead classes (in the hammermilled and fiberboards) and the results of the pH and buffering tests demonstrate that certainly no serious loss of compatibility for urea and phenolic resin has occurred in the dead material.

Let us turn now from the matter of retention of resin compatibility to the practical question of whether this resource can produce boards meeting present strength standards. The

data at hand only concern IB strength and represent only a first round of development. The next phase of the research was concerned more with the optimization and balance of properties. To address this question, we need to consider also the effect of specific gravity. Figures 15 and 16 plot IB strength against specific gravity according to species, resin type, and particle type. Plotted values are averaged over top and boles, all deterioration classes, and replicates. (For the drum-cut flakes of Figure 15, the means include the live classes with unmilled flakes. Had the values for remilled flakes been included instead, the flakeboard IB means would have been increased by 17 psi–0.12 MPa.) Horizontal lines in or bounding the shaded areas indicate the mean IB strengths required by some pertinent board standards.

In Figure 15 the required strength levels shown are for different classes and grades of board under Commercial Standard CS 236-66, "Mat-Formed Wood Particleboard." Boards from hammermilled particles all easily exceed these requirements, as would be expected for these rather short, blocky particles. Bending properties would be expected to be more critical in such boards.

Boards from drum-cut flakes, with their much higher length/thickness ratio, tend to have better bending properties, at the expense of IB strength. All the flakeboards at 0.85 specific gravity meet or exceed requirements for all grades under CS 236-66. Only the lower density (0.65) white pine flakeboards failed to meet any grade level of standards. Adjustment of resin amount, specific gravity, and control of flake geometry are all available means to optimize IB in relation to bending properties to meet end-use requirements or standards.

In Figure 16 for the fiberboard, the two standards indicated are the National Particleboard Association Standard NPA 4-73 for "Medium Density Fiberboard" and the Voluntary Product Standard PS58-73, "Basic Hardboard." In the NPA standard, medium density fiberboard must have a minimum IB of 100 psi (0.65 MPa). In PS58-73, this type of board is designated Class 5 "Industrialite" and must have an IB of at least 35 psi (0.24 MPa). All the experimental boards meet the latter specification, even at 0.65 specific gravity. To meet the 100 psi requirement of the NPA Standard would require a board density of about 0.75 specific gravity to qualify the lowest-strength boards (lodgepole–phenolic), which is about the usual specific gravity of medium-density fiberboard now made.

## Physical Properties

The IB properties were discussed under resin compatibility, as this test was necessary to determine whether bonding problems were present. In this part of the report MOR, MOE, water soak, and LE properties will be presented and discussed.

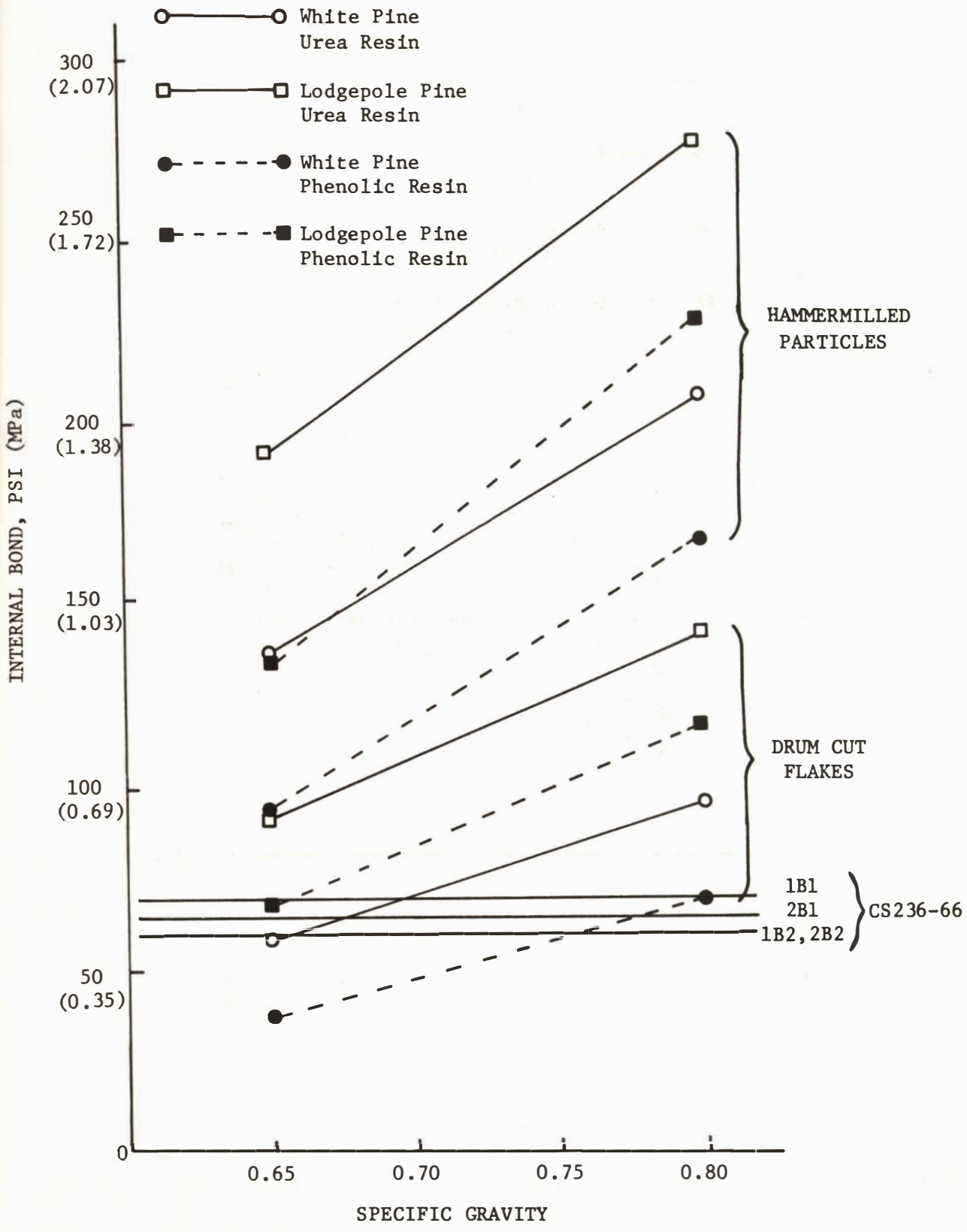



Figure 15. Comparison of Internal Bond Values of Boards Made from Hammermilled Particles and Drum-Cut Flakes with the Specifications in Commercial Standard CS236-66 "Mat-Formed Wood Particleboard."

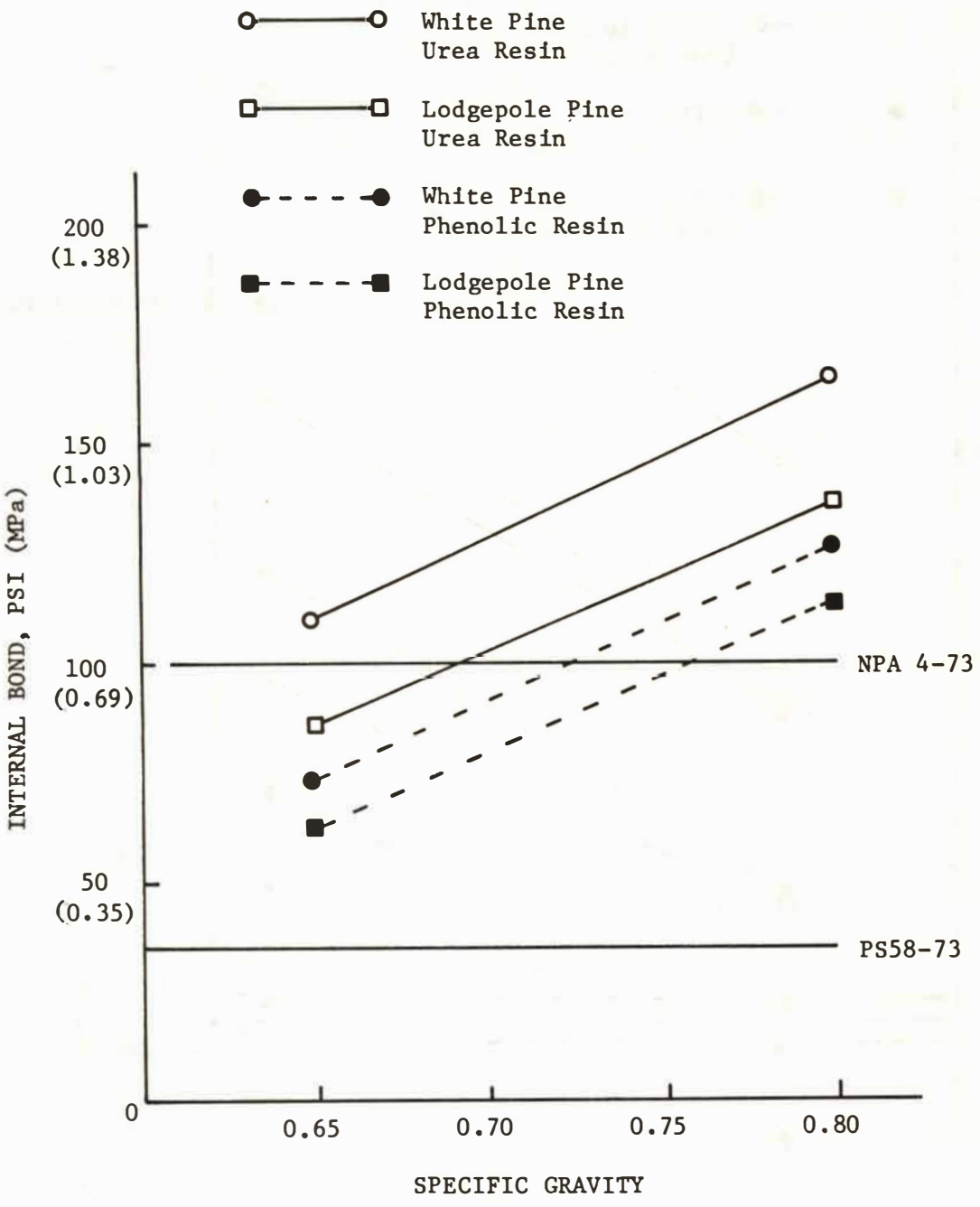



Figure 16. Comparison of Internal Bond Values of Boards Made from Pressure-Refined Fiber with the Specifications in the National Particleboard Association's Standard NPA 4-73 "Medium Density Fiberboard" and in Voluntary Product Standard PS58-73 "Basic Hardboard" Class 5 (Industrialite) Board.

## Modulus of Rupture and Modulus of Elasticity

Two MOR and two MOE evaluations were made on each board. For MOR and MOE there were 8 values per treatment (2 tests per board by 2 specific gravity levels by 2 replicates). The data was subjected to linear regression analysis for both properties on specific gravity to afford predicted means of these properties at the two nominal specific gravity levels of 0.65 and 0.85. Correlation coefficients were mostly above 0.9.

The MOR and MOE means, adjusted to the two nominal density levels, are shown in Tables 12-15. Analysis of the data can be performed in many ways that can yield several interpretations. Following the method of analysis used in discussing IB appears to be the best approach because of the relation of the test results among experimental variables. There were some differences in these comparisons, which can be seen in the tables. In general, it is possible to consider mean value for dead and for live material for each type of board and resin type. Therefore, to simplify the discussion, the data were grouped into live and dead, urea (UF) and phenolic (PF) resin for each species and type of particle used for board production.

Key information for this discussion is shown in Figures 17-22. Tables 16 and 17 present this information in tabular form. As with IB, MOR and MOE increase substantially with increased board density. Differences between species appeared negligible. Boards of hammer-milled particles were lowest in MOR value, as would be expected from their unfavorable particle geometry for developing high bending strengths. Boards of pressure-refined fiber and drum-cut flakes were about the same in bending strength because of the good length/thickness ratios of the particles.

In hammermilled particleboards of both species and both resins, live material afforded higher MOR than did dead material. These superior values were attributed to the better length/thickness ratios of the particles milled from live, green wood as opposed to the dry, dead wood. This is a normal result of the greater brittleness of dry, dead wood and implies that hammermilling dry material is not appropriate for developing maximum bending strength.

MOR of white pine fiberboards of live material made with phenolic resin was better than the other boards of dead material and boards of live material with urea resin. Fiberboards of lodgepole all had approximately the same MOR values.

Flakeboards of live material of both species had higher MOR in comparison to boards made from the dead classes. Since the flakes of both live and dead classes have relatively similar particle geometries, it seems that better bonding of the boards made with live material is primarily responsible for this difference in MOR.

MOR values were approximately the same for both species. MOE comparisons by particle type are not as clear-cut as for MOR. Boards of both species of hammermilled particles have

Table 12. Modulus of Rupture [psi (MPa)] Adjusted to 0.65 Specific Gravity.

| Species | | Deterioration Class | Top or Bole | Hammermilled Particles | | Pressure-Refined Fiber | | Drum-Cut Flakes | | Milled Drum-Cut Flakes | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Phenolic | Urea | Phenolic | Urea | Phenolic | Urea | Phenolic | Urea |
| White Pine | Standing Dead | A Red needles, bark mostly intact | B | 1270 ( 8.8) | 1490 (10.3) | 3830 (26.4) | 3090 (21.3) | 2180 (15.0) | 2480 (17.1) | | |
| | | | T | 1050 ( 7.2) | 1320 ( 9.1) | 4000 (27.6) | 4200 (29.0) | 2030 (14.0) | 2390 (16.5) | | |
| | | B No needles | B | 1040 ( 7.2) | 1430 ( 9.9) | 3770 (26.0) | 3120 (21.5) | 2100 (14.5) | 2730 (18.8) | | |
| | | | T | 1320 ( 9.1) | 1560 (10.8) | 3480 (24.0) | 3700 (25.5) | 2220 (15.3) | 2500 (17.2) | | |
| | | C Deep checks, weathering. No: twigs, small branches | B | 1270 ( 8.8) | 1460 (10.1) | 3880 (26.8) | 3140 (21.7) | 1930 (13.3) | 2430 (16.8) | | |
| | | | T | 1350 ( 9.3) | 1330 ( 9.2) | 3420 (23.6) | 2950 (20.3) | 2130 (14.7) | 2660 (18.3) | | |
| | Live | L Living trees | B | 1950 (13.5) | 2040 (14.1) | 4610 (31.8) | 4280 (29.5) | 2560 (17.7) | 3320 (22.9) | 3760 (25.9) | 3700 (25.5) |
| | | | T | 1990 (13.7) | 2290 (15.8) | 3930 (27.1) | 3480 (24.0) | 2590 (17.9) | 2820 (19.4) | 2880 (19.9) | 2900 (20.0) |
| Lodgepole Pine | Standing Dead | A As above | B | 1400 ( 9.7) | 1640 (11.3) | 4000 (27.6) | 3530 (24.3) | 2210 (15.2) | 2830 (19.5) | | |
| | | | T | 1020 ( 7.0) | 1050 ( 7.2) | 3960 (27.3) | 3590 (24.8) | 2280 (15.7) | 2150 (14.8) | | |
| | | B As above | B | 1110 ( 7.7) | 1070 ( 7.4) | 3450 (23.8) | 3570 (24.6) | 2080 (14.3) | 2460 (17.0) | | |
| | | | T | 1230 ( 8.5) | 1270 ( 8.8) | 3960 (27.3) | 3520 (24.3) | 2220 (15.3) | 2300 (15.9) | | |
| | | C As above | B | 1080 ( 7.5) | 1340 ( 9.2) | 4120 (28.4) | 3920 (27.0) | 2330 (16.1) | 2740 (18.9) | | |
| | | | T | 1070 ( 7.4) | 1220 ( 8.4) | 3720 (25.7) | 3580 (24.7) | 2200 (15.2) | 2570 (17.7) | | |
| | Down | D Same as C but not standing | B | 1100 ( 7.6) | 1080 ( 7.5) | 3520 (24.3) | 3160 (21.8) | 1960 (13.5) | 2340 (16.1) | | |
| | | | T | 1010 ( 7.0) | 1370 ( 9.5) | 3100 (21.4) | 3420 (23.6) | 1990 (13.7) | 2060 (14.2) | | |
| | Live | L Living trees | B | 2200 (15.2) | 2210 (15.2) | 3890 (26.8) | 3910 (27.0) | 3200 (22.1) | 3620 (25.0) | 3540 (24.4) | 3290 (22.7) |
| | | | T | 2190 (15.1) | 2020 (13.9) | 3870 (26.7) | 4000 (27.6) | 3140 (21.7) | 3100 (21.4) | 3120 (21.5) | 3020 (20.8) |

Table 13. Modulus of Rupture [psi (MPa)] Adjusted to 0.85 Specific Gravity.

| Species | | Deterioration Class | Top or Bole | Hammermilled Particles | | Pressure-Refined Fiber | | Drum-Cut Flakes | | Milled Drum-Cut Flakes | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Phenolic | Urea | Phenolic | Urea | Phenolic | Urea | Phenolic | Urea |
| White Pine | Standing Dead | A Red needles, bark mostly intact | B | 3200 (22.1) | 3040 (21.0) | 6560 (45.2) | 5620 (38.7) | 4410 (30.4) | 4740 (32.7) | | |
| | | | T | 2880 (19.8) | 3050 (21.0) | 6870 (47.4) | 7000 (48.3) | 3910 (26.9) | 4120 (28.4) | | |
| | | B No needles | B | 2770 (19.1) | 3020 (20.8) | 6490 (44.7) | 6760 (46.6) | 4010 (27.6) | 4530 (31.2) | | |
| | | | T | 3150 (21.7) | 2900 (20.0) | 6730 (46.4) | 6290 (43.4) | 4180 (28.8) | 4390 (30.3) | | |
| | | C Deep checks, weathering. No: twigs, small branches | B | 2800 (19.3) | 2670 (18.4) | 6460 (44.5) | 5990 (41.3) | 4000 (27.6) | 4640 (32.0) | | |
| | | | T | 2900 (20.0) | 2850 (19.6) | 5830 (40.2) | 5240 (36.1) | 4080 (28.1) | 4440 (30.6) | | |
| | Live | L Living trees | B | 3630 (25.0) | 3680 (25.4) | 8290 (57.1) | 6680 (46.0) | 5280 (36.4) | 5400 (37.2) | 5740 (39.6) | 6260 (43.2) |
| | | | T | 3810 (26.3) | 4280 (29.5) | 7510 (51.8) | 6020 (41.5) | 4730 (32.6) | 4820 (33.2) | 4860 (33.5) | 5020 (34.6) |
| Lodgepole Pine | Standing Dead | A As above | B | 3250 (22.4) | 3310 (22.8) | 7330 (50.5) | 6290 (43.4) | 4430 (30.5) | 4460 (30.7) | | |
| | | | T | 2770 (19.1) | 2820 (19.4) | 8480 (58.5) | 6710 (46.3) | 4200 (28.9) | 4380 (30.2) | | |
| | | B As above | B | 2790 (19.2) | 2960 (20.4) | 6700 (46.2) | 5990 (41.3) | 4460 (30.7) | 4450 (30.7) | | |
| | | | T | 2930 (20.2) | 3020 (20.8) | 7300 (50.3) | 5800 (40.0) | 4380 (30.2) | 4050 (27.9) | | |
| | | C As above | B | 2830 (19.5) | 2960 (20.4) | 7420 (51.2) | 7160 (49.4) | 4090 (28.2) | 4650 (32.1) | | |
| | | | T | 2840 (19.6) | 2990 (20.6) | 7510 (51.8) | 6410 (44.2) | 4810 (33.2) | 4530 (31.2) | | |
| | Down | D Same as C but not standing | B | 2520 (17.4) | 2700 (18.6) | 6770 (46.7) | 6250 (43.1) | 4230 (29.2) | 3940 (27.2) | | |
| | | | T | 2720 (18.8) | 2820 (19.4) | 7140 (49.2) | 6040 (41.6) | 3630 (25.0) | 4130 (28.5) | | |
| | Live | L Living trees | B | 4430 (30.5) | 4600 (31.7) | 6870 (47.4) | 6760 (46.6) | 6230 (42.9) | 5580 (38.5) | 5790 (39.9) | 5560 (38.3) |
| | | | T | 4200 (28.9) | 4190 (28.9) | 6960 (48.0) | 6430 (44.3) | 6010 (41.4) | 5090 (35.1) | 5700 (39.3) | 5300 (36.5) |

Table 14. Modulus of Elasticity [psi x $10^6$ (MPa)] Adjusted to 0.65 Specific Gravity.

| Species | | Deterioration Class | Top or Bole | Hammermilled Particles | | Pressure-Refined Fiber | | Drum-Cut Flakes | | Milled Drum-Cut Flakes | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Phenolic | Urea | Phenolic | Urea | Phenolic | Urea | Phenolic | Urea |
| White Pine | Standing Dead | A Red needles, bark mostly intact | B | 0.194 (1338) | 0.205 (1413) | 0.288 (1986) | 0.259 (1785) | 0.376 (2592) | 0.380 (2620) | | |
| | | | T | 0.188 (1296) | 0.228 (1572) | 0.324 (2234) | 0.350 (2413) | 0.342 (2358) | 0.369 (2544) | | |
| | | B No needles | B | 0.217 (1496) | 0.217 (1496) | 0.305 (2103) | 0.279 (1924) | 0.345 (2379) | 0.401 (2765) | | |
| | | | T | 0.273 (1882) | 0.240 (1655) | 0.278 (1917) | 0.334 (2303) | 0.364 (2510) | 0.416 (2868) | | |
| | | C Deep checks, weathering. No: twigs, small branches | B | 0.244 (1682) | 0.229 (1579) | 0.316 (2179) | 0.278 (1917) | 0.358 (2468) | 0.388 (2675) | | |
| | | | T | 0.257 (1772) | 0.220 (1517) | 0.283 (1951) | 0.254 (1751) | 0.376 (2592) | 0.404 (2786) | | |
| | Live | L Living Trees | B | 0.304 (2096) | 0.313 (2158) | 0.345 (2379) | 0.366 (2524) | 0.466 (3213) | 0.497 (3427) | 0.522 (3599) | 0.533 (3675) |
| | | | T | 0.269 (1855) | 0.343 (2364) | 0.355 (2448) | 0.326 (2248) | 0.422 (2910) | 0.434 (2992) | 0.447 (3082) | 0.440 (3034) |
| Lodgepole Pine | Standing Dead | A As above | B | 0.240 (1655) | 0.244 (1682) | 0.382 (2634) | 0.333 (2296) | 0.325 (2201) | 0.411 (2834) | | |
| | | | T | 0.158 (1089) | 0.197 (1358) | 0.402 (2772) | 0.349 (2406) | 0.347 (2392) | 0.349 (2406) | | |
| | | B As above | B | 0.216 (1489) | 0.195 (1344) | 0.268 (1848) | 0.291 (2006) | 0.318 (2193) | 0.356 (2455) | | |
| | | | T | 0.219 (1510) | 0.209 (1441) | 0.408 (2813) | 0.354 (2441) | 0.349 (2406) | 0.350 (2413) | | |
| | | C As above | B | 0.201 (1386) | 0.220 (1517) | 0.372 (2565) | 0.385 (2654) | 0.356 (2455) | 0.403 (2779) | | |
| | | | T | 0.211 (1455) | 0.215 (1482) | 0.319 (2199) | 0.355 (2448) | 0.337 (2324) | 0.354 (2441) | | |
| | Down | D Same as C but not standing | B | 0.201 (1386) | 0.168 (1158) | 0.323 (2227) | 0.307 (2117) | 0.321 (2213) | 0.359 (2475) | | |
| | | | T | 0.212 (1462) | 0.287 (1979) | 0.318 (2193) | 0.345 (2379) | 0.300 (2068) | 0.305 (2103) | | |
| | Live | L Living trees | B | 0.337 (2324) | 0.309 (2130) | 0.368 (2537) | 0.369 (2544) | 0.449 (3096) | 0.508 (3503) | 0.481 (3316) | 0.425 (2930) |
| | | | T | 0.318 (2193) | 0.278 (1917) | 0.318 (2193) | 0.305 (2103) | 0.428 (2951) | 0.422 (2910) | 0.436 (3006) | 0.394 (2717) |

Table 15. Modulus of Elasticity [psi x $10^6$ (MPa)] Adjusted to 0.85 Specific Gravity.

| Species | | Deterioration Class | Top or Bole | Hammermilled Particles | | Pressure-Refined Fiber | | Drum-Cut Flakes | | Milled Drum-Cut Flakes | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Phenolic | Urea | Phenolic | Urea | Phenolic | Urea | Phenolic | Urea |
| White Pine | Standing Dead | A Red needles, bark mostly intact | B | 0.479 (3303) | 0.447 (3082) | 0.504 (3475) | 0.444 (3061) | 0.731 (5040) | 0.649 (4475) | | |
| | | | T | 0.479 (3303) | 0.483 (3330) | 0.580 (3999) | 0.577 (3978) | 0.623 (4296) | 0.627 (4323) | | |
| | | B No needles | B | 0.496 (3420) | 0.471 (3247) | 0.528 (3640) | 0.537 (3703) | 0.647 (4461) | 0.705 (4861) | | |
| | | | T | 0.560 (3861) | 0.514 (3544) | 0.525 (3620) | 0.540 (3723) | 0.662 (4564) | 0.688 (4744) | | |
| | | C Deep checks, weathering. No: twigs, small branches | B | 0.505 (3482) | 0.458 (3158) | 0.542 (3737) | 0.512 (3530) | 0.642 (4426) | 0.704 (4854) | | |
| | | | T | 0.523 (3606) | 0.483 (3330) | 0.487 (3358) | 0.476 (3282) | 0.691 (4764) | 0.692 (4771) | | |
| | Live | L Living trees | B | 0.552 (3806) | 0.544 (3751) | 0.683 (4709) | 0.597 (4116) | 0.773 (5330) | 0.739 (5095) | 0.789 (5440) | 0.793 (5468) |
| | | | T | 0.521 (3592) | 0.596 (4109) | 0.547 (3771) | 0.541 (3730) | 0.747 (5150) | 0.709 (4888) | 0.727 (5013) | 0.686 (4730) |
| Lodgepole Pine | Standing Dead | A As above | B | 0.480 (3310) | 0.468 (3227) | 0.612 (4220) | 0.553 (3813) | 0.662 (4564) | 0.641 (4420) | | |
| | | | T | 0.409 (2820) | 0.450 (3103) | 0.678 (4675) | 0.629 (4337) | 0.659 (4544) | 0.582 (4013) | | |
| | | B As above | B | 0.488 (3365) | 0.458 (3158) | 0.509 (3509) | 0.502 (3461) | 0.655 (4516) | 0.591 (4075) | | |
| | | | T | 0.504 (3475) | 0.480 (3310) | 0.604 (4164) | 0.550 (3792) | 0.658 (4537) | 0.612 (4220) | | |
| | | C As above | B | 0.504 (3475) | 0.469 (3234) | 0.612 (4220) | 0.612 (4220) | 0.655 (4516) | 0.637 (4392) | | |
| | | | T | 0.528 (3640) | 0.517 (3565) | 0.612 (4220) | 0.557 (3840) | 0.684 (4716) | 0.698 (4813) | | |
| | Down | D Same as C but not standing | B | 0.478 (3296) | 0.425 (2930) | 0.568 (3916) | 0.564 (3888) | 0.652 (4495) | 0.569 (3923) | | |
| | | | T | 0.488 (3365) | 0.442 (3047) | 0.567 (3909) | 0.539 (3716) | 0.593 (4089) | 0.591 (4075) | | |
| | Live | L Living trees | B | 0.623 (4295) | 0.589 (4061) | 0.640 (4413) | 0.592 (4082) | 0.811 (5592) | 0.741 (5109) | 0.734 (5061) | 0.693 (4778) |
| | | | T | 0.604 (4164) | 0.552 (3806) | 0.545 (3758) | 0.500 (3447) | 0.742 (5116) | 0.727 (5013) | 0.746 (5144) | 0.704 (4854) |

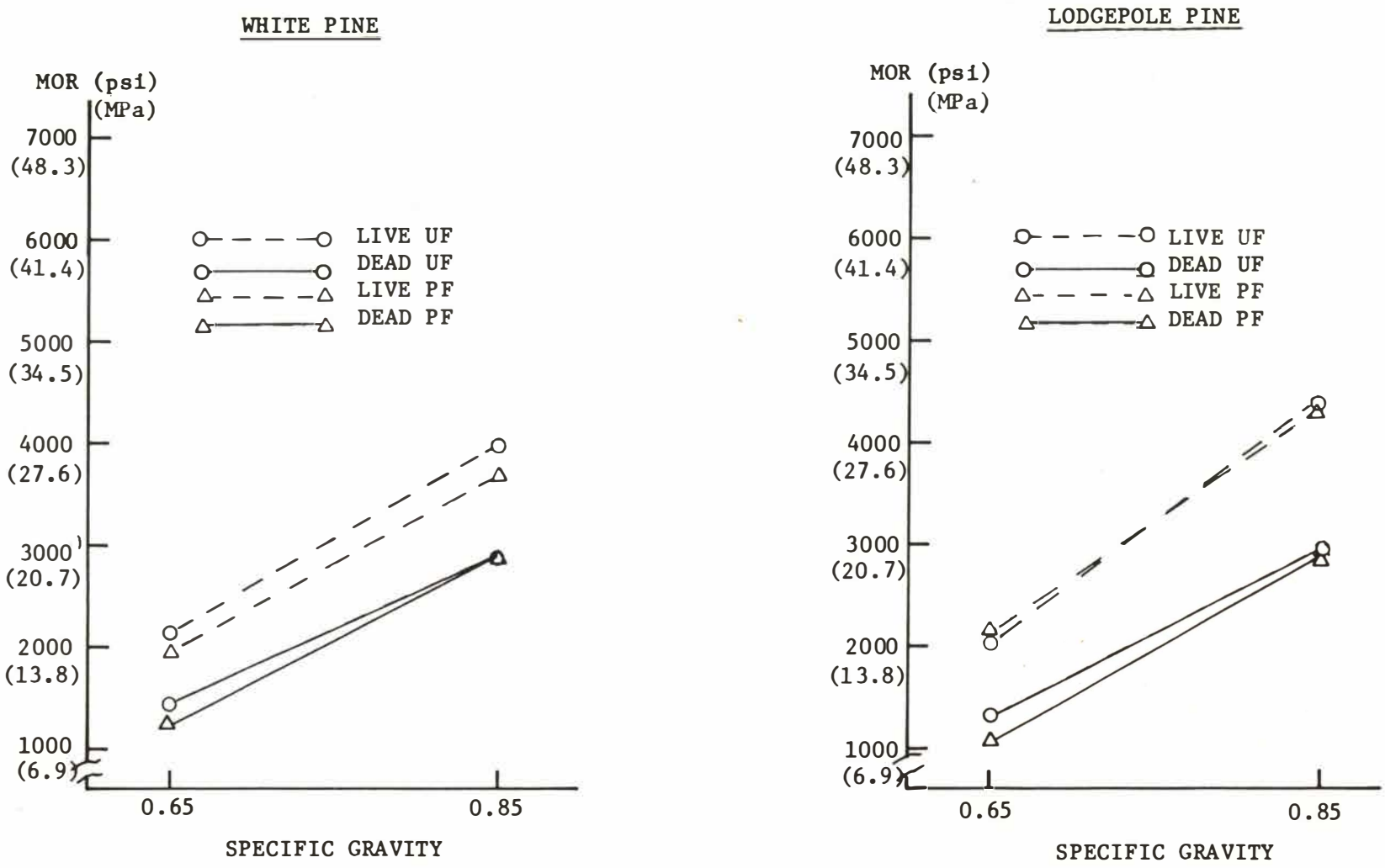



Figure 17. Specific Gravity vs. Modulus of Rupture for Boards of Hammermilled Particles.

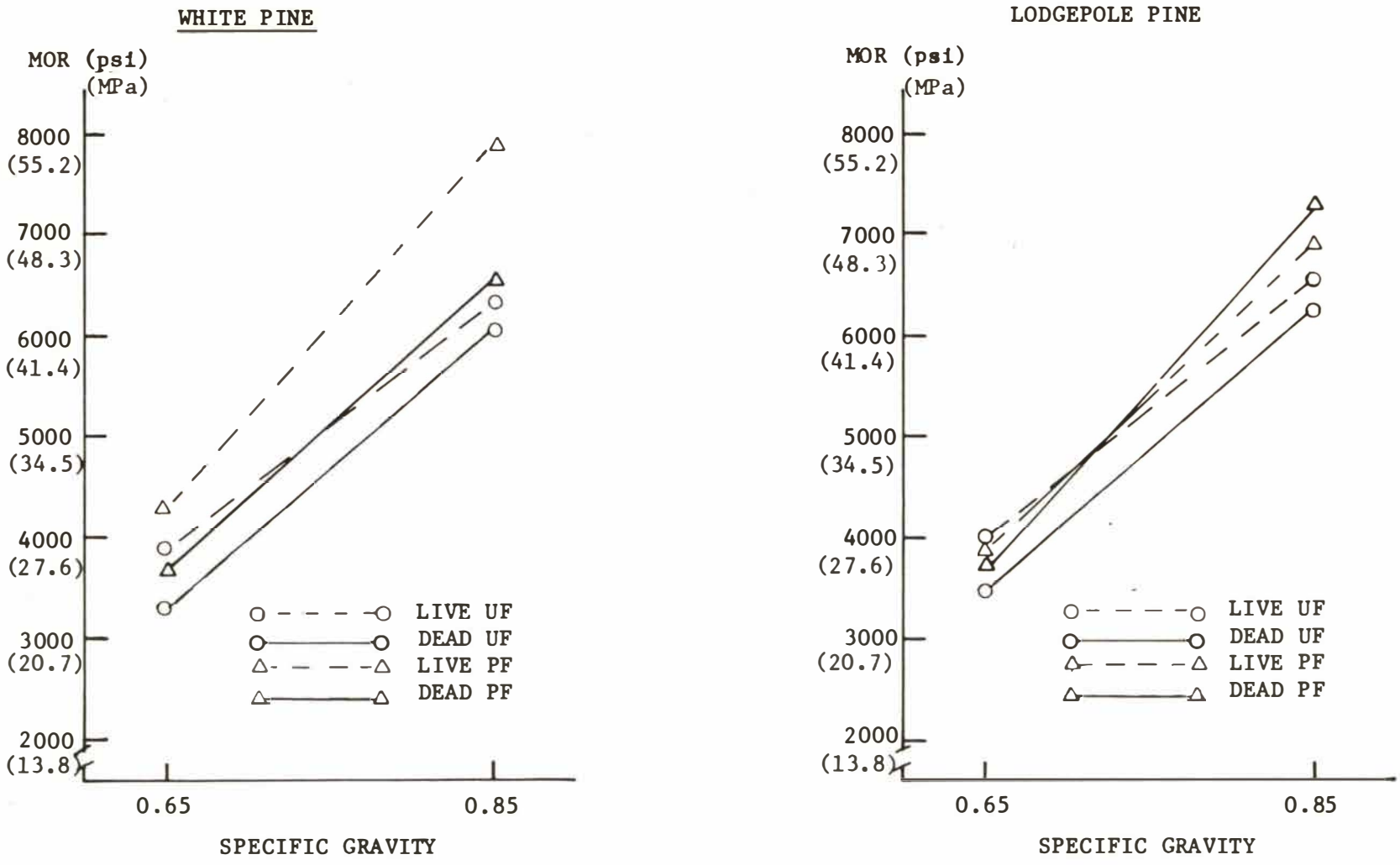



Figure 18. Specific Gravity vs. Modulus of Rupture for Boards of Pressure-Refined Fiber.

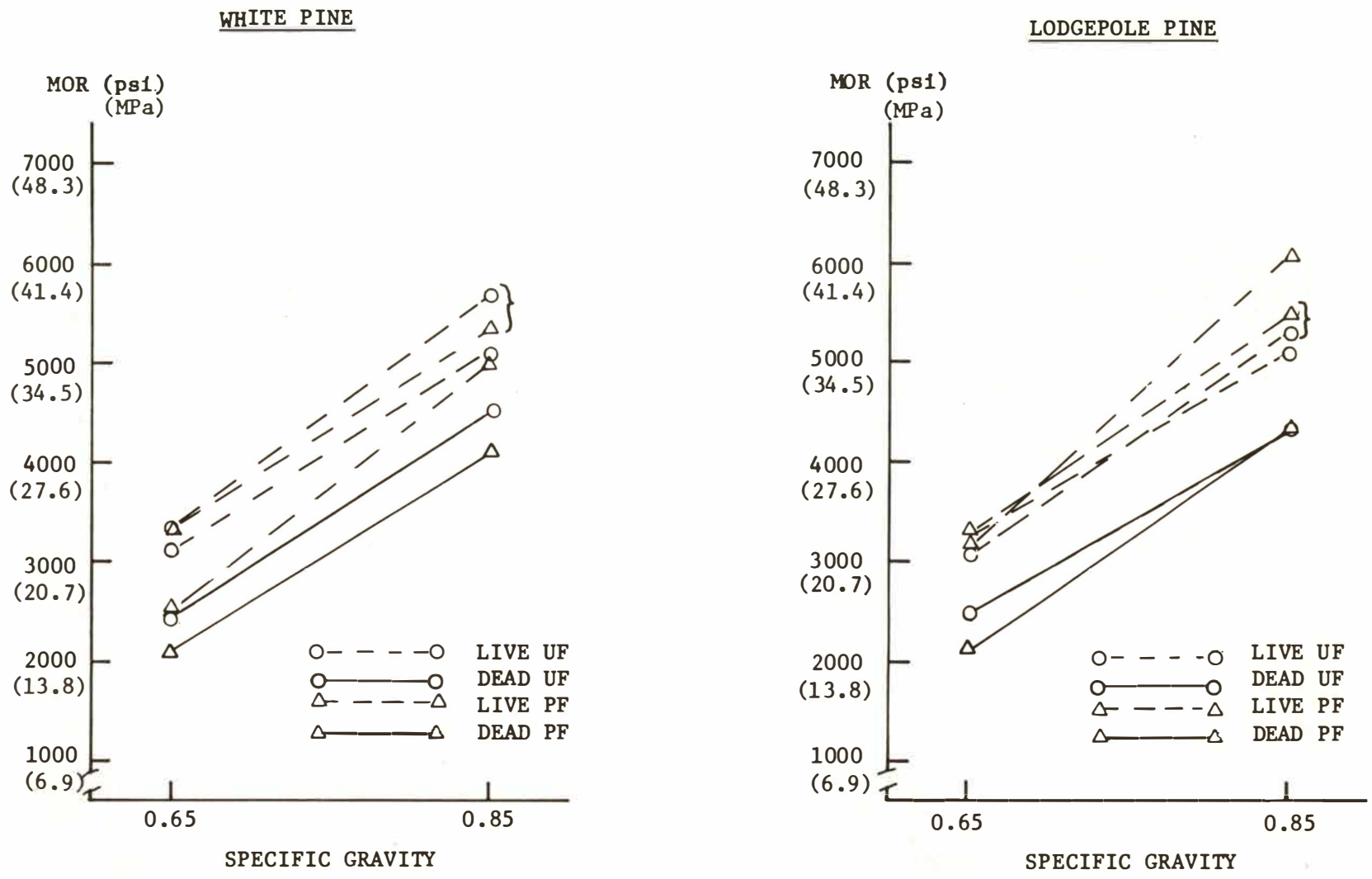



Figure 19. Specific Gravity vs. Modulus of Rupture for Boards of Drum-Cut Flakes.

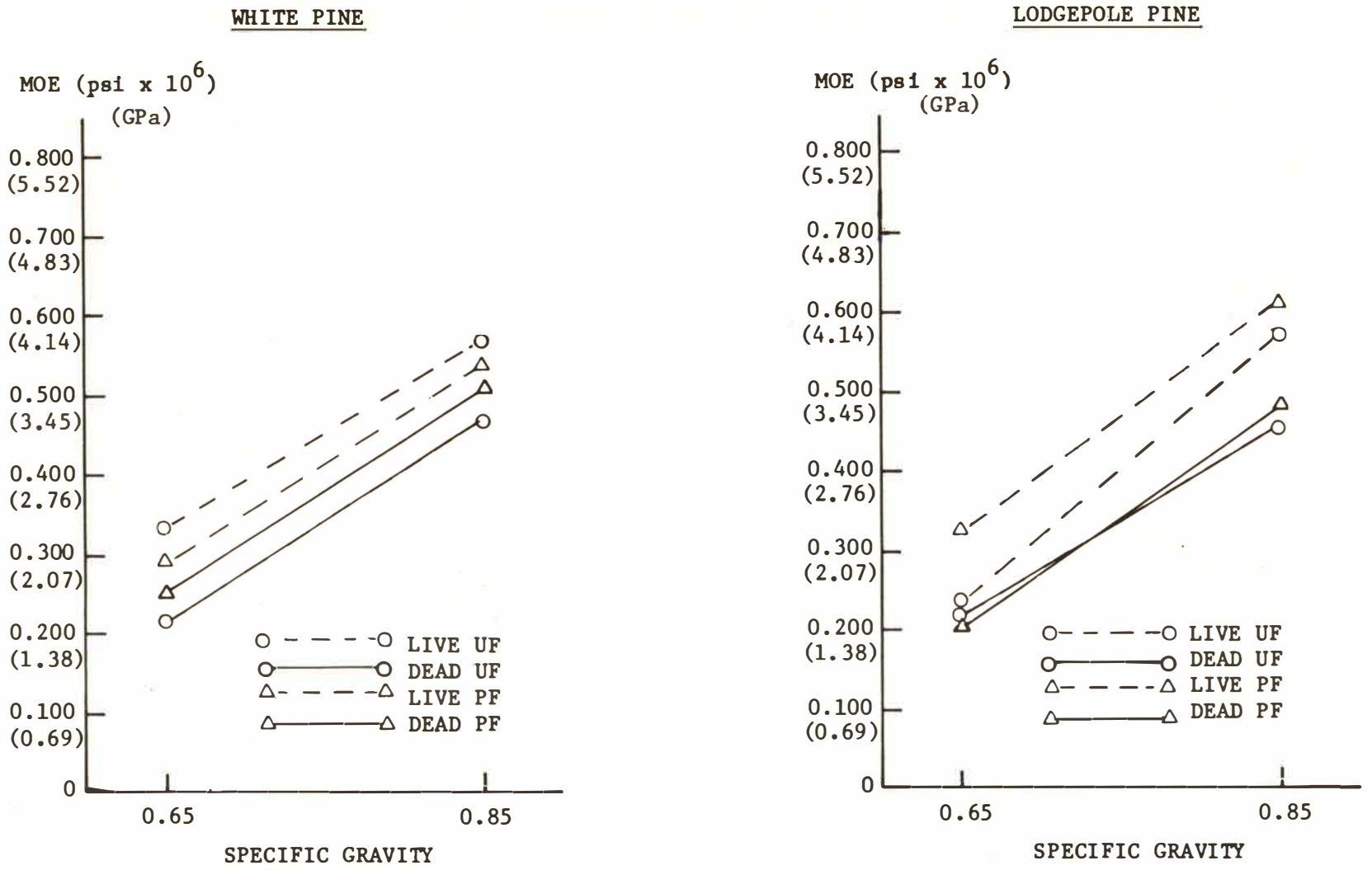



Figure 20. Specific Gravity vs. Modulus of Elasticity for Boards of Hammermilled Particles.

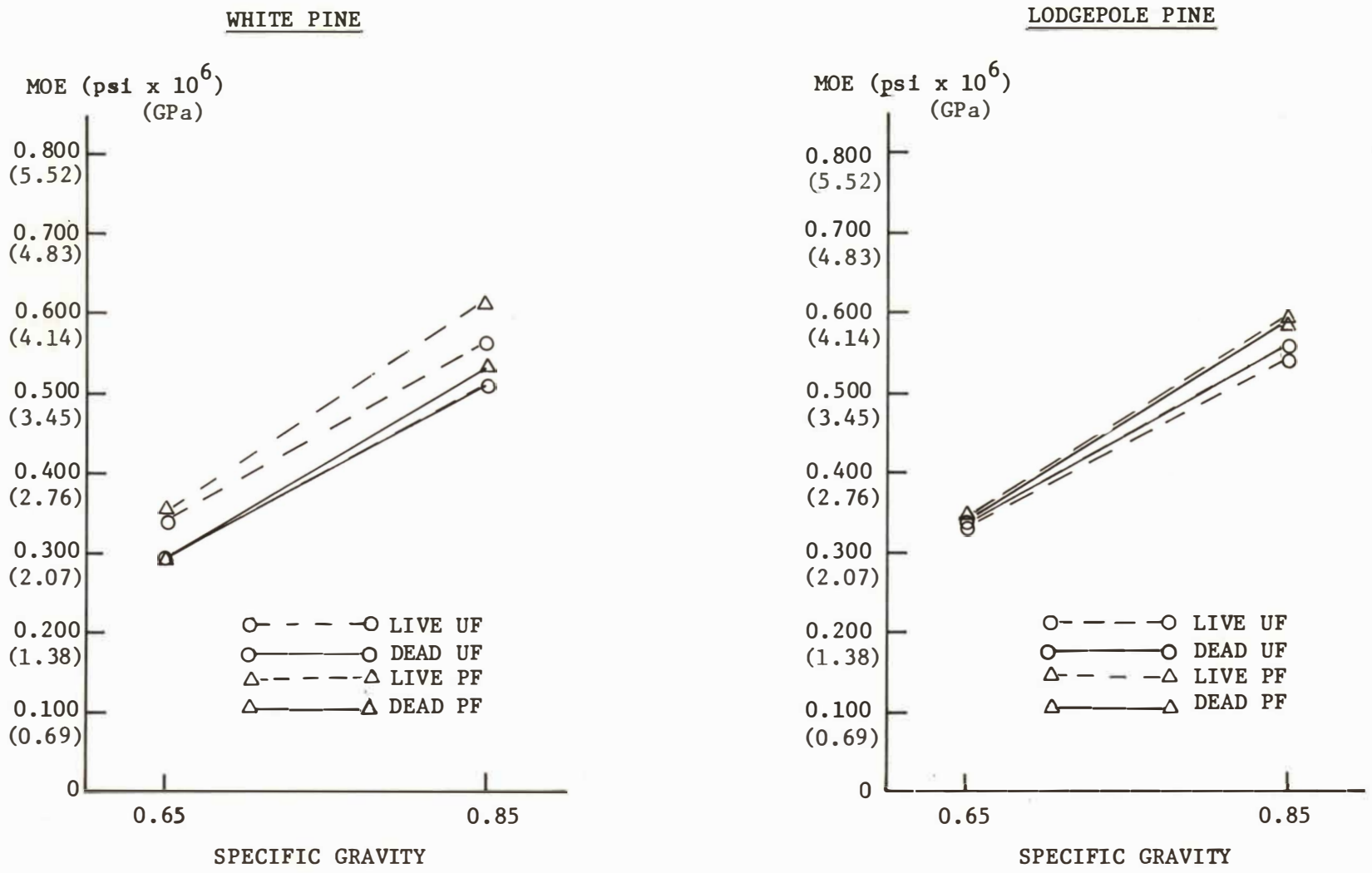



Figure 21. Specific Gravity vs. Modulus of Elasticity for Boards of Pressure-Refined Fiber.

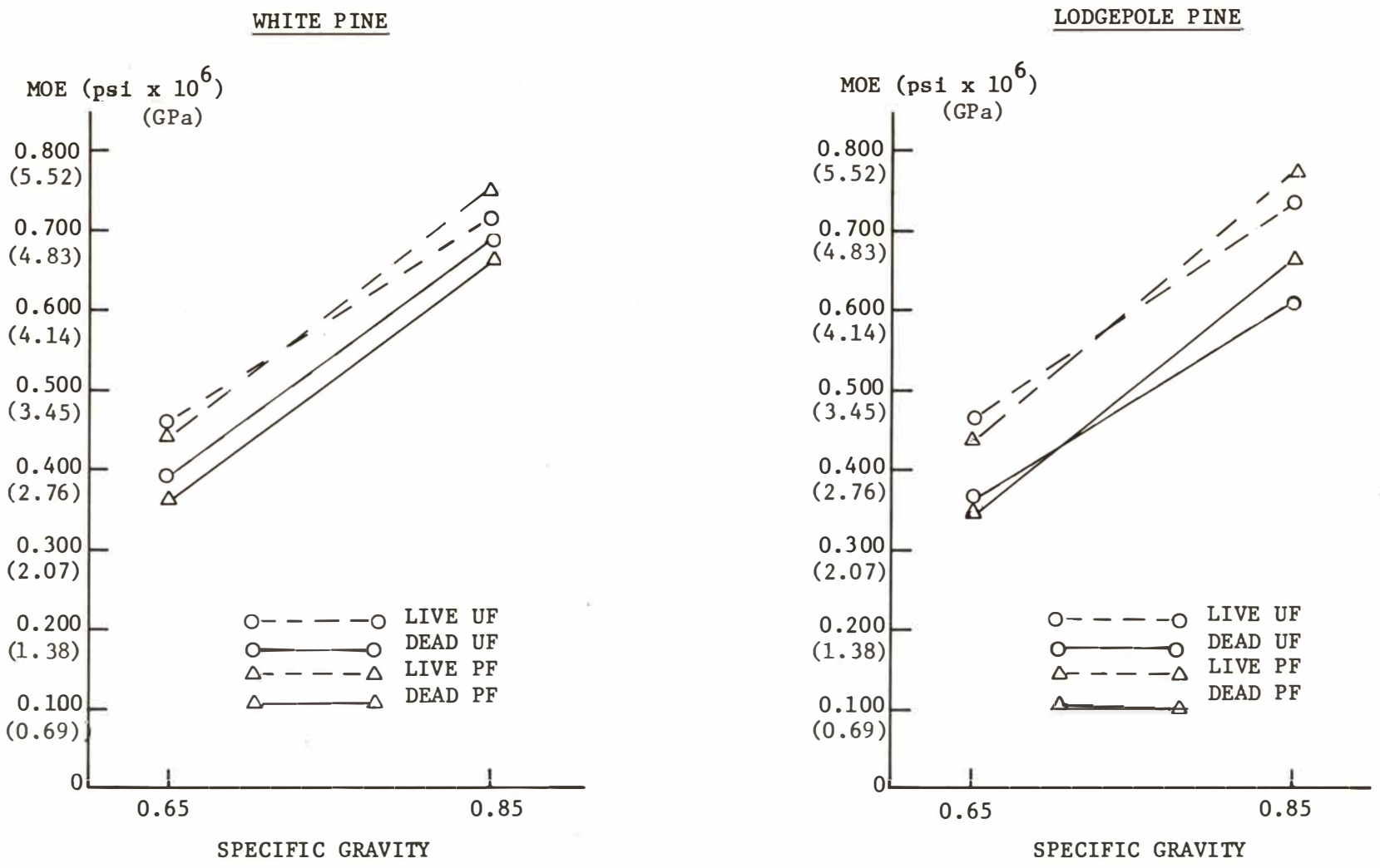



Figure 22. Specific Gravity vs. Modulus of Elasticity for Boards of Drum-Cut Flakes. Milled Live Values Are Approximately the Same as Those Shown for the Live Class.

Table 16. Average Modulus of Rupture [psi (MPa)] for Combined Dead Classes and Live Classes at Both Specific Gravity Levels.

| Species | | Hammermilled Particles | | | | Pressure-Refined Fiber | | | | Drum-Cut Flakes | | | | Milled Drum-Cut Flakes | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Phenolic (4%) | | Urea (7%) | | Phenolic (7%) | | Urea (9%) | | Phenolic (4%) | | Urea (7%) | | Phenolic (4%) | | Urea (7%) | |
| | | 0.65 | 0.85 | 0.65 | 0.85 | 0.65 | 0.85 | 0.65 | 0.85 | 0.65 | 0.85 | 0.65 | 0.85 | 0.65 | 0.85 | 0.65 | 0.85 |
| White Pine | Dead | 1210 (8.3) | 2950 (20.3) | 1430 (9.8) | 2920 (20.1) | 3730 (25.7) | 6490 (44.7) | 3370 (23.2) | 6150 (42.4) | 2100 (14.5) | 4100 (28.3) | 2530 (17.4) | 4480 (30.9) | | | | |
| | Live | 1970 (13.6) | 3720 (25.6) | 2160 (14.9) | 3980 (27.4) | 4270 (29.4) | 7900 (54.5) | 3880 (26.7) | 6350 (43.8) | 2570 (17.7) | 5000 (34.5) | 3070 (21.2) | 5110 (35.2) | 3320 (22.9) | 5300 (36.5) | 3100 (22.7) | 5640 (38.9) |
| Lodgepole | Dead | 1120 (7.7) | 2830 (19.5) | 1250 (8.6) | 2950 (20.3) | 3720 (25.6) | 7330 (50.5) | 3530 (24.3) | 6330 (43.6) | 2150 (14.8) | 4280 (29.5) | 2430 (16.7) | 4320 (29.8) | | | | |
| | Live | 2190 (15.1) | 4310 (29.7) | 2110 (14.5) | 4390 (30.3) | 3880 (26.7) | 6910 (47.6) | 3950 (27.2) | 6590 (45.4) | 3170 (21.8) | 6120 (42.2) | 3360 (23.2) | 5330 (36.7) | 3330 (22.9) | 5740 (39.6) | 3150 (21.7) | 5430 (37.4) |

Table 17. Average Modulus of Elasticity [psi x $10^6$ (MPa)] for Combined Dead Classes and Live Classes at Both Specific Gravity Levels.

| | | Hammermilled Particles | | | | Pressure-Refined Fiber | | | | Drum-Cut Flakes | | | | Milled Drum-Cut Flakes | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Phenolic (4%) | | Urea (7%) | | Phenolic (7%) | | Urea (9%) | | Phenolic (4%) | | Urea (7%) | | Phenolic (4%) | | Urea (7%) | |
| | | 0.65 | 0.85 | 0.65 | 0.85 | 0.65 | 0.85 | 0.65 | 0.85 | 0.65 | 0.85 | 0.65 | 0.85 | 0.65 | 0.85 | 0.65 | 0.85 |
| White Pine | Dead | 0.228 (1572) | 0.507 (3495) | 0.223 (1537) | 0.476 (3281) | 0.299 (2061) | 0.528 (3640) | 0.292 (2013) | 0.514 (3543) | 0.359 (2475) | 0.666 (4591) | 0.392 (2702) | 0.677 (4667) | | | | |
| | Live | 0.286 (1972) | 0.536 (3695) | 0.328 (2261) | 0.570 (3929) | 0.350 (2413) | 0.615 (4240) | 0.346 (2385) | 0.569 (3923) | 0.444 (3061) | 0.760 (5239) | 0.465 (3206) | 0.724 (4991) | 0.484 (3337) | 0.758 (5226) | 0.486 (3350) | 0.739 (5095) |
| Lodgepole | Dead | 0.270 (1427) | 0.485 (3344) | 0.216 (1489) | 0.464 (3199) | 0.349 (2406) | 0.595 (4102) | 0.340 (2344) | 0.563 (3881) | 0.331 (2282) | 0.652 (4495) | 0.360 (2482) | 0.615 (4240) | | | | |
| | Live | 0.327 (2254) | 0.613 (4226) | 0.293 (2020) | 0.570 (3929) | 0.343 (2365) | 0.592 (4081) | 0.337 (2323) | 0.546 (3764) | 0.438 (3019) | 0.776 (5349) | 0.465 (3206) | 0.734 (5060) | 0.458 (3157) | 0.740 (5102) | 0.409 (2819) | 0.698 (4812) |

MOE values for the live classes a bit higher than for the dead classes. Hammermilled particles of live material have better particle geometries, as mentioned previously, and this is probably the reason for the higher MOE in boards of hammermilled live material.

White pine fiberboards of live material are slightly better in MOE than boards from the dead classes. No differences by class appear with lodgepole pine.

The MOE values for the fiberboards were not much higher than those for the boards of hammermilled particles. It would be expected usually that there would be a much greater difference. While not measured, however, the fiberboards probably had lower-density surfaces than the comparable boards of hammermilled particles. The level of the face density has great influence on MOE. The fiberboards as made had soft surfaces which had to be planed off to simulate the normal practice of sanding. These soft surfaces are not unusual with fiberboards made according to the specifications for this study. After planing, the face density of the boards may not have been as high as in the boards of hammermilled particles. Thus, the MOE's of the fiberboards were lower than they might have been.

Boards of drum-cut flakes are highest in MOE value, which was anticipated because of the good geometry of the drum-cut flakes. Boards of flakes from live material for both species were slightly higher in MOE. Both species were about the same in MOE, depending upon resin level and class of material.

## 24-Hour Water-Soak Properties

Because of the aforementioned problem of obtaining sufficient test specimens from the 11 by 14 in. (279 by 356 mm) experimental panels, the size of the water soak specimens was reduced from the minimum specified in 6 in. (152 mm) sq to 4.5 in. (114 mm) sq. Smaller specimens absorb more water than larger ones because of an edge effect–more edge area is exposed on the smaller specimen, based in relation to the amount of surface area. Water is absorbed faster through the edges because of the lower density in the core as compared to the face of the panel and to planar directionality of the void space and permeability of the panel.

The data were handled by averaging the low and high specific gravity values for the respective species, classes, type of board, and different resins. Plotting of these properties vs. specific gravity showed that little difference occurred with change in board specific gravity; therefore, linear regression analysis was not of value when considering these properties and was not performed. There were four values per treatment obtained, as there was only one test per board.

Twenty-four hour water-soak properties are very difficult to interpret. The two properties measured, thickness swell (TS) and water absorption (WA), have been found to be highly

species-dependent; e.g., boards of Douglas-fir have excellent properties, while comparable boards of aspen have much higher absorption and swell. The test is also of a very short duration; therefore, these specimens do not come to equilibrium conditions. The amount of wax in the boards is also of importance, as the wax inhibits the pickup of water during the test. Optimum wax levels were not determined for the material under study, but the level used in the study (0.75%) is representative of industry practice.

Comparisons between live and dead material within a species should be of primary interest in this phase of work. Tables 18 and 19 present 24-hour water-soak results arranged by deterioration class. Table 20 combines these data for easier comparison.

The WA and TS values at the 0.85 density are lower than at the 0.65 specific gravity levels because the water cannot penetrate the higher density boards as quickly as the lower density boards during the 24-hour test period.

In general, the values observed for the dead and live classes within each species were approximately the same, thus indicating no adverse effects from the dead material. With boards of pressure-refined fiber of white pine, boards from dead material bonded with urea were much lower in WA and TS at both density levels than were boards bonded with phenolic. Lodgepole boards of live material bonded with phenolic were lower in these properties than the boards from dead material, but boards with urea resin were about the same in these properties. These differences may be due to experimental error as reflected in low values for certain classes, but this type of confusing information has appeared frequently in water-absorption tests.

A dramatic improvement in water-soak properties was exhibited by the boards made of live, milled, drum-cut flakes. WA and TS were both reduced tremendously. This can be attributed to better IB and better intermeshing of the smaller flakes, which slowed the absorption of water.

## Linear Expansion

The LE data were handled the same as the 24-hour water-soak data. Four values were obtained per treatment.

Considerable confusion exists with this test, as much higher than expected moisture absorptions (MA) occurred, resulting in higher thickness swells (TS) and linear expansions (LE). The specimens are conditioned first at 50% relative humidity (RH) at 70°F. They are then placed in a 90% RH atmosphere while maintaining the 70°F temperature. Wood so conditioned would have a 9.2% moisture content at 50% RH and 20.5% moisture content at 90% RH. Composition boards are usually slightly lower in equilibrium moisture content at both humidities because they

Table 18. Response to 24-Hour Water Soak at 0.65 Nominal Specific Gravity.

| Species | | Deterioration | Top or Bole | Hammermilled Particles | | | | Pressure-Refined Fiber | | | | Drum-Cut Flakes | | | | Milled Drum-Cut Flakes, Reground | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Phenolic | | Urea | | Phenolic | | Urea | | Phenolic | | Urea | | Phenolic | | Urea | |
| | | | | TS(%) | WA(%) | TS(%) | WA(%) | TS(%) | WA(%) | TS(%) | WA(%) | TS(%) | WA(%) | TS(%) | WA(%) | TS(%) | WA(%) | TS(%) | WA(%) |
| White Pine | Standing Dead | A Red needles, bark mostly intact | B | 16.0 | 48.5 | 14.7 | 36.9 | 7.6 | 41.1 | 6.7 | 18.1 | 21.0 | 75.0 | 11.4 | 36.7 | | | | |
| | | | T | 12.4 | 40.9 | 14.6 | 36.6 | 12.6 | 58.2 | 7.5 | 20.2 | 20.7 | 70.1 | 18.8 | 51.6 | | | | |
| | | B No needles | B | 18.1 | 68.7 | 13.4 | 37.5 | 8.0 | 40.2 | 6.9 | 16.5 | 22.4 | 89.8 | 16.6 | 41.8 | | | | |
| | | | T | 17.3 | 67.7 | 15.9 | 45.8 | 9.9 | 54.1 | 7.6 | 25.2 | 22.7 | 90.4 | 22.8 | 65.5 | | | | |
| | | C Deep checks, weathering. No. twigs, sm. branches | B | 18.8 | 69.7 | 14.5 | 38.8 | 7.4 | 34.7 | 8.5 | 22.3 | 22.4 | 80.8 | 15.9 | 38.4 | | | | |
| | | | T | 18.1 | 64.0 | 14.8 | 43.1 | 9.3 | 45.5 | 7.9 | 25.9 | 24.3 | 91.2 | 23.8 | 62.7 | | | | |
| | Live | L Living trees | B | 15.5 | 48.6 | 13.0 | 29.5 | 9.1 | 43.5 | 10.9 | 26.2 | 24.7 | 74.6 | 20.2 | 47.5 | 9.9 | 38.0 | 9.4 | 24.9 |
| | | | T | 18.6 | 55.5 | 11.4 | 28.9 | 14.8 | 56.5 | 16.3 | 37.9 | 21.5 | 78.0 | 17.9 | 48.3 | 12.4 | 45.1 | 10.9 | 26.8 |
| Lodgepole Pine | Standing Dead | A As above | B | 11.8 | 36.6 | 13.4 | 30.7 | 13.6 | 65.6 | 8.3 | 18.8 | 13.9 | 52.5 | 10.9 | 29.5 | | | | |
| | | | T | 16.2 | 49.5 | 14.7 | 34.4 | 11.5 | 50.5 | 9.6 | 22.9 | 17.7 | 64.2 | 13.9 | 43.6 | | | | |
| | | B As above | B | 13.5 | 47.2 | 14.2 | 35.9 | 9.3 | 41.3 | 7.3 | 17.6 | 15.4 | 52.7 | 14.1 | 42.2 | | | | |
| | | | T | 13.6 | 42.0 | 14.0 | 30.1 | 14.3 | 58.5 | 13.5 | 21.4 | 21.2 | 79.3 | 25.7 | 76.7 | | | | |
| | | C As above | B | 11.0 | 37.3 | 12.0 | 24.1 | 12.9 | 62.2 | 7.7 | 18.3 | 19.9 | 73.8 | 15.3 | 45.8 | | | | |
| | | | T | 10.5 | 41.2 | 12.3 | 31.2 | 12.7 | 70.1 | 8.7 | 19.2 | 14.6 | 56.7 | 15.7 | 50.6 | | | | |
| | Down | D Same as C but not standing | B | 10.3 | 33.4 | 13.5 | 34.8 | 14.8 | 69.5 | 13.3 | 34.3 | 17.9 | 81.2 | 19.3 | 66.8 | | | | |
| | | | T | 16.1 | 52.4 | 14.6 | 36.3 | 16.2 | 65.3 | 13.2 | 29.1 | 20.5 | 92.9 | 22.4 | 86.2 | | | | |
| | Live | L Living trees | B | 10.9 | 35.6 | 11.1 | 25.3 | 9.2 | 34.8 | 8.9 | 22.8 | 18.7 | 57.6 | 13.8 | 39.8 | 10.4 | 34.7 | 12.8 | 36.0 |
| | | | T | 9.8 | 43.2 | 11.9 | 32.8 | 6.5 | 27.7 | 6.8 | 17.2 | 24.5 | 66.5 | 17.3 | 49.6 | 11.9 | 37.7 | 11.0 | 36.4 |

Table 19. Response to 24-Hour Water Soak at 0.85 Nominal Specific Gravity.

| Species | Deterioration Class | Top or Bole | Hammermilled Particles | | | | Pressure-Refined Fiber | | | | Drum-Cut Flakes | | | | Milled Drum-Cut Flakes, Reground | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Phenolic | | Urea | | Phenolic | | Urea | | Phenolic | | Urea | | Phenolic | | Urea | |
| | | | TS(%) | WA(%) | TS(%) | WA(%) | TS(%) | WA(%) | TS(%) | WA(%) | TS(%) | WA(%) | TS(%) | WA(%) | TS(%) | WA(%) | TS(%) | WA(%) |
| White Pine Standing Dead | A Red needles, bark mostly intact | B | 13.6 | 30.4 | 9.4 | 13.2 | 6.8 | 30.7 | 6.1 | 14.4 | 22.8 | 53.9 | 9.8 | 23.6 | | | | |
| | | T | 10.6 | 24.5 | 12.0 | 17.5 | 11.5 | 40.4 | 6.6 | 16.4 | 22.7 | 66.9 | 15.8 | 32.4 | | | | |
| | B No needles | B | 16.3 | 39.5 | 12.8 | 24.4 | 5.7 | 26.1 | 5.7 | 12.9 | 26.3 | 66.5 | 12.2 | 24.3 | | | | |
| | | T | 19.6 | 48.5 | 13.8 | 29.5 | 8.7 | 38.0 | 6.9 | 18.3 | 26.7 | 68.6 | 22.1 | 41.4 | | | | |
| | C Deep checks, weathering. No: twigs, sm. branches | B | 15.1 | 36.7 | 13.2 | 26.9 | 5.3 | 20.4 | 7.2 | 16.8 | 26.5 | 67.2 | 12.0 | 23.3 | | | | |
| | | T | 17.7 | 44.7 | 13.3 | 27.1 | 6.8 | 26.5 | 7.7 | 21.1 | 27.9 | 67.8 | 26.1 | 47.8 | | | | |
| White Pine Live | L Living trees | B | 15.5 | 34.1 | 10.6 | 18.6 | 6.1 | 22.8 | 9.9 | 21.1 | 30.6 | 54.4 | 16.6 | 26.9 | 8.9 | 22.8 | 7.3 | 14.0 |
| | | T | 17.8 | 37.7 | 9.1 | 14.6 | 10.5 | 34.8 | 17.0 | 36.4 | 24.5 | 53.7 | 14.2 | 27.6 | 10.1 | 26.6 | 9.0 | 17.7 |
| Lodgepole Pine Standing Dead | A As above | B | 10.8 | 22.6 | 10.8 | 18.1 | 14.0 | 53.0 | 7.2 | 14.9 | 13.5 | 31.5 | 9.9 | 19.7 | | | | |
| | | T | 13.3 | 24.0 | 12.3 | 20.4 | 7.5 | 25.7 | 8.3 | 15.9 | 15.6 | 36.6 | 11.5 | 24.5 | | | | |
| | B As above | B | 10.8 | 21.4 | 9.4 | 13.8 | 7.0 | 31.0 | 6.4 | 14.0 | 14.6 | 34.9 | 9.4 | 15.7 | | | | |
| | | T | 13.4 | 29.0 | 12.8 | 23.6 | 15.2 | 53.1 | 11.8 | 28.0 | 21.4 | 49.7 | 19.9 | 40.6 | | | | |
| | C As above | B | 9.9 | 19.9 | 10.6 | 16.3 | 12.5 | 47.4 | 6.2 | 13.2 | 20.7 | 50.3 | 11.6 | 25.5 | | | | |
| | | T | 8.8 | 21.7 | 12.3 | 23.2 | 12.6 | 54.6 | 6.6 | 13.4 | 12.8 | 33.9 | 13.5 | 31.4 | | | | |
| Lodgepole Pine Down | D Same as C but not standing | B | 9.4 | 22.9 | 12.1 | 19.8 | 14.3 | 52.3 | 11.2 | 26.7 | 19.7 | 50.6 | 18.6 | 39.1 | | | | |
| | | T | 13.2 | 28.1 | 13.2 | 22.4 | 13.6 | 42.1 | 12.3 | 28.2 | 25.1 | 66.9 | 23.9 | 55.4 | | | | |
| Lodgepole Pine Live | L Living trees | B | 11.5 | 19.8 | 8.9 | 16.7 | 7.9 | 27.3 | 8.4 | 18.0 | 16.0 | 36.9 | 12.8 | 28.0 | 8.7 | 21.2 | 9.6 | 21.2 |
| | | T | 12.7 | 27.1 | 10.3 | 19.4 | 4.7 | 17.6 | 5.8 | 13.3 | 17.4 | 39.5 | 13.5 | 29.8 | 10.3 | 25.8 | 10.2 | 22.4 |

Table 20. Response to 24-Hour Water Soak Average Values for Combined Dead Classes and Live at Both Specific Gravity Levels.

Hammermilled Particles

| Species | Phenolic | | | | Urea | | | |
|---|---|---|---|---|---|---|---|---|
| | 0.65 | | 0.85 | | 0.65 | | 0.85 | |
| | TS(%) | WA(%) | TS(%) | WA(%) | TS(%) | WA(%) | TS(%) | WA(%) |
| White Pine-Dead | 16.8 | 59.9 | 15.5 | 37.4 | 14.7 | 39.8 | 12.4 | 23.1 |
| White Pine-Live | 17.1 | 52.1 | 16.7 | 35.9 | 12.2 | 29.2 | 9.9 | 16.6 |
| Lodgepole-Dead | 12.9 | 39.6 | 11.2 | 23.7 | 13.6 | 32.2 | 11.7 | 19.7 |
| Lodgepole-Live | 10.4 | 39.4 | 12.1 | 23.5 | 11.5 | 29.1 | 9.6 | 18.1 |

Pressure-Refined Fiber

| Species | Phenolic | | | | Urea | | | |
|---|---|---|---|---|---|---|---|---|
| | 0.65 | | 0.85 | | 0.65 | | 0.85 | |
| | TS(%) | WA(%) | TS(%) | WA(%) | TS(%) | WA(%) | TS(%) | WA(%) |
| White Pine-Dead | 9.1 | 45.6 | 7.5 | 30.4 | 7.5 | 21.4 | 6.7 | 16.7 |
| White Pine-Live | 12.0 | 50.0 | 8.3 | 28.8 | 13.6 | 32.1 | 13.5 | 28.8 |
| Lodgepole-Dead | 13.2 | 60.4 | 12.1 | 44.9 | 10.2 | 22.7 | 8.8 | 19.3 |
| Lodgepole-Live | 7.9 | 31.3 | 6.3 | 22.5 | 7.9 | 20.0 | 7.1 | 15.7 |

Drum-Cut Flakes

| Species | Phenolic | | | | Urea | | | |
|---|---|---|---|---|---|---|---|---|
| | 0.65 | | 0.85 | | 0.65 | | 0.85 | |
| | TS(%) | WA(%) | TS(%) | WA(%) | TS(%) | WA(%) | TS(%) | WA(%) |
| White Pine-Dead | 22.3 | 82.9 | 25.5 | 65.2 | 18.2 | 49.5 | 16.3 | 32.1 |
| White Pine-Live | 23.1 (11.2)* | 76.3 (41.6) | 27.6 (9.5) | 54.1 (24.7) | 19.1 (10.2) | 47.9 (25.9) | 15.4 (8.2) | 27.3 (15.9) |
| Lodgepole-Dead | 17.6 | 69.2 | 17.9 | 44.3 | 17.2 | 55.2 | 14.8 | 31.5 |
| Lodgepole-Live | 21.6 (11.2) | 62.1 (36.2) | 16.7 (9.5) | 38.2 (23.5) | 15.6 (11.9) | 44.7 (36.2) | 13.2 (9.9) | 28.9 (21.8) |

* ( ) Milled live flakes.

contain resin and wax that are less hygroscopic and because exposure to high temperature in pressing tends to reduce the hygroscopicity of the wood.

The data are presented in Table 21. The moisture absorptions were mostly about 13-14% except for urea-bonded boards of pressure-refined fiber, where moisture absorbed was 18-29%. All of these absorptions were higher than should be expected, but the fiberboard data are completely out of line. Considerable mold, however, formed on the fiberboards, and it is likely that this was largely responsible for the higher "moisture absorptions."

If the experimental error is considered as constant for all material evaluated, some relationships can be noted.

In boards of hammermilled particles, live classes were better in LE than dead. This is to be expected, however, as the better particle geometry—i.e., good length-thickness ratios—minimizes LE. The blockier particles of the dead classes in a board result in much higher LE values.

For fiberboard, the live class of white pine exhibited the lower expansion, and the reverse was true for lodgepole. The excessive moisture absorption clouds this comparison.

As would be expected because of the excellent length/thickness ratios of the drum-cut flakes, boards made of these particles had low linear expansions. For practical purposes the dead and live classes of each species had the same expansion properties.

## Phase 1 Conclusions

The major conclusion of this phase of the research was that the dead classes of white pine and lodgepole pine could be used effectively for various types of composition board. Some refinements of the board-producing parameters are needed to optimize commercial board formulations, but these would be minor and reasonable changes according to today's board technology. Of the particles studied, hammermilled, ring-cut, atmospheric- and pressure-refined fiber appeared to be best. Structural flakeboards of drum-cut flakes had low internal bond, indicating gluing problems with such flakes cut from dry dead material.

Several conclusions can be made on boards evaluated for IB, MOR, MOE, 24-hour water-soak responses, and LE. Differences in IB occurred between live and dead classes in some cases, whereas no great differences were observed otherwise. Phenolic bonded, hammermilled particleboards of dead lodgepole pine were better than those from live lodgepole. Fiberboards (pressure-refined fiber) of live material bonded with urea were better than those of dead material. Flakeboards of drum-cut flakes from live and dead material were quite low in IB.

Table 21. Response to 90% Relative Humidity Exposure, Average Value for Combined Dead Classes and Live at Both Specific Gravity Levels.

Hammermilled Particles

| Species | Phenolic | | | | | | Urea | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0.65 | | | 0.85 | | | 0.65 | | | 0.85 | | |
| | LE(%) | MA(%) | TS(%) | LE(%) | MA(%) | TS(%) | LE(%) | MA(%) | TS(%) | LE(%) | MA(%) | TS(%) |
| White Pine - Dead | 0.33 | 13.6 | 16.2 | 0.30 | 12.9 | 16.7 | 0.46 | 13.3 | 19.4 | 0.42 | 12.7 | 20.0 |
| White Pine - Live | 0.21 | 13.5 | 18.7 | 0.20 | 12.9 | 18.8 | 0.27 | 13.4 | 20.5 | 0.31 | 12.7 | 21.1 |
| Lodgepole - Dead | 0.52 | 14.4 | 15.4 | 0.48 | 13.7 | 16.5 | 0.74 | 13.9 | 18.9 | 0.65 | 13.1 | 18.7 |
| Lodgepole - Live | 0.26 | 13.6 | 16.7 | 0.30 | 12.6 | 15.5 | 0.39 | 13.7 | 18.4 | 0.39 | 12.7 | 17.0 |

Pressure-Refined Fiber

| Species | Phenolic | | | | | | Urea | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0.65 | | | 0.85 | | | 0.65 | | | 0.85 | | |
| | LE(%) | MA(%) | TS(%) | LE(%) | MA(%) | TS(%) | LE(%) | MA(%) | TS(%) | LE(%) | MA(%) | TS(%) |
| White Pine - Dead | 0.56 | 14.9 | 13.0 | 0.52 | 14.3 | 13.2 | 0.81 | 18.6 | 23.9 | 0.87 | 18.4 | 27.1 |
| White Pine - Live | 0.26 | 15.8 | 14.3 | 0.25 | 14.5 | 14.0 | 0.59 | 20.5 | 27.1 | 0.66 | 20.1 | 29.9 |
| Lodgepole - Dead | 0.23 | 14.5 | 12.8 | 0.23 | 13.8 | 12.9 | 0.47 | 18.2 | 21.8 | 0.51 | 17.8 | 23.8 |
| Lodgepole - Live | 0.37 | 15.2 | 14.5 | 0.37 | 14.6 | 14.9 | 0.57 | 18.9 | 24.2 | 0.61 | 18.5 | 26.9 |

Drum-Cut Flakes

| Species | Phenolic | | | | | | Urea | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0.65 | | | 0.85 | | | 0.65 | | | 0.85 | | |
| | LE(%) | MA(%) | TS(%) | LE(%) | MA(%) | TS(%) | LE(%) | MA(%) | TS(%) | LE(%) | MA(%) | TS(%) |
| White Pine - Dead | 0.06 | 13.8 | 20.2 | 0.05 | 13.3 | 21.3 | 0.10 | 13.7 | 20.2 | 0.10 | 13.1 | 21.3 |
| White Pine - Live | 0.07 | 13.3 | 20.5 | 0.07 | 12.9 | 21.8 | 0.08 | 13.9 | 22.4 | 0.10 | 13.7 | 23.6 |
| | (0.07)* | (13.0) | (14.9) | (0.08) | (12.6) | (16.6) | (0.11) | (13.5) | (17.6) | (0.12) | (12.9) | (18.4) |
| Lodgepole - Dead | 0.13 | 14.8 | 18.5 | 0.14 | 14.1 | 19.7 | 0.16 | 14.3 | 18.9 | 0.20 | 13.7 | 20.1 |
| Lodgepole - Live | 0.14 | 14.4 | 21.2 | 0.20 | 13.6 | 16.7 | 0.18 | 14.7 | 21.0 | 0.22 | 14.1 | 21.9 |
| | (0.17) | (14.1) | (19.5) | (0.19) | (13.2) | (15.8) | (0.21) | (14.8) | (20.3) | (0.24) | (13.5) | (18.9) |

* ( ) Milled live flakes.

Milling the wide flakes from live material into narrow widths resulted in an approximate doubling of the IB.

In MOR, hammermilled particleboards of live material were best because of superior particle geometry (better length/thickness ratio). Fiberboards were all about the same except for better bending in boards of white pine (live material) bonded with phenolic. Flakeboards of live material were better in MOR than those of dead material.

With a few exceptions, MOE was about the same for each species when comparable particles were used. Hammermilled particleboards of live material of both species were better than those of dead material because of the better particle geometry. Fiberboards of live white pine exhibited MOE's that were slightly greater than those of dead classes. Flakeboards had the highest MOE values, with live class material higher in stiffness than the dead classes.

Boards from live and dead classes for all these board types were about the same in 24-hour water soak responses.

In LE, more moisture was absorbed than expected, which seems to be a species effect. Some unidentified mold formed on the urea-bonded fiberboards. Hammermilled particleboards of live material were lower in LE and therefore best in comparison to dead material. This was due to the better particle geometry of the live material. Fiberboards of dead white pine were higher in LE than live, while the reverse was true with lodgepole. Flakeboards were very low in LE and were best in this property.

Standing dead white pine and lodgepole pine, as sampled for this study, retained to a remarkable degree their original properties important to use in composition board products—even after many years of standing dead. The types of deterioration which prevent its use in lumber and plywood, such as deep checking, widespread sapstain, and pockets of decay, did have appreciable adverse effects on those aspects of suitability for composition board considered in this phase of the study.

Sapstain, which was widespread, apparently has little effect on milling properties or resin compatibility.

Actual decay, in the form of saprot or heartrot, was present in such small amounts (overall much less than one percent) that it has negligible effect when uniformly dispersed through the furnish, as occurs automatically in board manufacture.

Deep checking caused some additional surface to be exposed to weathering and oxidation, but the depth of the surface effects is so slight that nearly all of the new surface formed in any of the particle-generating processes is new, unweathered surface.

The measurable chemical properties (pH and buffering capacity) important to resin compatibility, particularly with urea resin, are essentially unchanged from the live wood and are in a range easily accommodated by present practices in the industry.

The amounts of usable particle furnish that can be made by the five particle-making methods studied are high and not appreciably different than with live trees of the same species.

A wide spectrum of particles, ranging from crude hammermilled chips through sophisticated pressure-refined fiber, can be generated from this material, capable of meeting the needs of many different types of board plants. Optimum particle-generating techniques were not established, and better results could be expected with such optimization. Excellent fiber of very low bulk density was produced by simple atmospheric attrition milling, and it is assumed that quality fiber could also be made at higher densities.

Resin blending with the flakes and hammermilled particles used long-established laboratory procedures believed to simulate closely industrial blending conditions. The resin-blending technique used with the fiber was improvised with available equipment and does not represent optimum procedure which might be developed for a board plant.

Two aspects in which the dead material differed markedly from the live were in the amounts of bark and moisture present, both decreasing with elapsed time from death of the trees. In present composition board practice, the loss of bark would be considered an advantage. The reduced moisture content (mostly below fiber saturation) would have important advantages in reducing transportation and drying costs and should reduce the rate of deterioration in stored logs or chips.

Moisture content had marked effect on power requirement in hammermilling of chips—the less moisture, the less power required. Power requirement was little affected by moisture in the other milling methods for which measurements were made. Because of the very short runs involved, the measured power requirements should be considered only as approximations, but the relatively very low power requirement for drum-flaking could be of considerable economic significance. Also, because of the short runs, no estimate could be made of the effect of the drier dead material on knife life and required sharpening frequency.

Moisture content of the raw material also affects the geometry of particles generated by hammermilling and by drum flaking and can thus affect the mechanical properties of the boards. Complete assessment of these effects must await the next phase of this study, but the effect on internal bond is clear: lower moisture content at milling gives higher internal bond strength. In drum-cut flakes, the particle geometry can be modified after the flaking and drying operations by light attrition milling of the flakes to split them to narrower width and thus approximate the geometry of flakes made at lower moisture content, if desired. Moisture content of chips could be adjusted to optimum levels before ring-flaking or hammermilling operations if needed, but logs for drum-flaking would presumably be flaked at the moisture content as received.

## PHASE 2: PRODUCTION OF TYPICAL COMMERCIAL COMPOSITION BOARDS

After the Phase 1 research was concluded, Phase 2 was initiated to demonstrate the feasibility of using the various types of particles generated in Phase 1 in typical composition boards. The composition boards made in Phase 1 of hammermilled particles, drum-cut flakes, and pressure-refined fiber were simple homogeneous boards; i.e., the particles were randomly mixed throughout the board. Particle geometry and resin compatibility were the primary concern in the first part of this research.

Much commercial board is not made with a homogeneous mix of particles, however, as advantage is taken of the different particle geometries to enhance board properties.

Furniture core board, for example, is made with a layered configuration as far as particles are concerned. Fine particles on the faces and coarse particles in the core is the normal lay-up, as the smooth board faces are needed for subsequent overlaying or print finishing. Mixing flakes with hammermilled particles is a popular way to improve bending and stiffness properties over those boards made solely of hammermilled particles.

Of the initial boards made, those of pressure-refined fiber made with urea resin can be considered as typical industrial boards, although there is some evidence that the urea resin level at times is higher than the 9% used in this study. Phenolic resin is used for house siding products made from fiber but usually at specific gravities above 0.85. Large flakes, such as the drum-cut ones, are used for "structural" boards; but the resin levels are higher than those used in the first phase of this study, which was evaluating resin sensitivity. Low levels of about 2-3% of powdered resin are used in the waferboard industry, but these flakes are about twice as thick as those made for this study. With a greater thickness, there is less total surface area of the flakes in a given board, as compared to thin flakes. Thus, ignoring interactions, it can be generally stated that less resin is needed with the thicker flakes.

It was felt that only the boards of pressure-refined fiber made in the Phase I research with urea resin could be called "typical" commercial boards. These were designated "medium density fiberboard" for the second phase of the research. Other typical commercial boards were then made using the particles generated in Phase I.

Prior to the actual board making, however, check boards were made to determine if any reduction in properties had developed due to aging of the particles since the completion of Phase I (all particles were kept in sealed plastic bags). These check boards were made identically to those made in Phase I. The physical properties of the check boards were compared with those obtained previously. No significant changes were noted, and the particles were deemed acceptable for the next phase of research.

Only material from the dead classes was used. In Phase I there did not appear to be an interaction between the dead material and resin. Therefore, in this part of the research, equal

parts of each material class for each particle type were mixed together to make up the furnish to be used in making the various typical boards. An exception was made in the case of the hardboards, where two classes from each species were used for board making. These classes were handled separately; and, as will be seen in the results, there were negligible differences between the classes.

The material classes were handled in this way to reduce the number of boards that would otherwise have had to be made when handling the classes separately. This was not possible to do under the financial limitations on this project.

The different typical boards made were underlayment, furniture core, door core, structural flakeboard, and hardboard. Details on the production of these follow.

Six replicates (of each species) for each type of board were made, with the exception of the door core and the hardboard. The door core was made in much larger sizes, as will be noted later; therefore, three boards were made, as sufficient material for use was available in the three boards. It was difficult to properly randomize the various classes of fiber; therefore, it was decided to make hardboards from two classes of material rather than from a randomized mix of all dead classes. Twenty-four hardboards of each species were made. Both atmospheric- and pressure-refined fiber was used from the two classes of material considered. Six replicates were made for each species–fiber type–class for a total of 48 boards.

Where six replicates were made, half were tested and half were retained for use as samples. The remaining material from the door core panels after tests was also retained for use as samples.

For board production, each species was handled separately. All boards with the exception of door core were made 12 by 15 in. [11 by 14 in. (279 by 356 mm) trimmed in size.] Door core is very thick; thus, larger boards were made so that bending specimens of proper lengths [36 in. (914 mm)] could be cut. Important board specifications were:

| Board Type | Panel Thickness | | Nominal Specific Gravity | Resin Level |
|---|---|---|---|---|
| | in. | mm | | |
| Underlayment | 0.680 | 17.3 | 0.64 | 6 |
| Furniture Core | 0.680 | 17.3 | 0.72 | 6% Core<br>11% Face |
| Door Core | 1.50 | 38.1 | 0.49 | 6% Core<br>11% Face |
| Structural Flakeboard | 0.680 | 17.3 | 0.72 | 6 |
| Hardboard | 0.125 | 3.2 | 1.0 | 3 |

Resins used were supplied by Borden Chemical Company and Georgia-Pacific Corporation. The wax emulsion was a Borden product applied at 0.75% in all boards.

Particle geometries varied by product. Tabulated below are the particles used for the various products:

| Board Type | Particle Types And Amounts |
|---|---|
| Underlayment | 50% hammermilled particles (-6+42 Tyler screen size)<br>50% air-classified, ring-cut flakes [flakes over 0.020 in. (0.51 mm) in thickness removed] |
| Furniture Core (Three-Layer) | Furnish same as used for Underlayment<br>Faces: 23% of the total for each face, -20 screen size particles<br>Core: 54% of the total +20 screen size particles |
| Door Core (Three-Layer) | Furnish same as used for Underlayment<br>Faces: 15% of the total for each face, -20 screen size particles<br>Core: 70% of the total, +20 screen size particles |
| Structural Flakeboard* (Three-Layer) | Faces: 20% of +9 drum-cut flakes for each face<br>Core: 60% of a mixture of +9 and -9 drum-cut flakes (The larger flakes were used in the faces to enhance bending properties.) |
| Hardboard | Pressure-refined fiber<br>Atmospheric-refined fiber |

* "Structural particleboard" is not a conventional product in the U.S. The term is being used here generically to cover a wide variety of possible products. Ring-cut flakes could be used as well as drum-cut flakes.

## Board Producing Techniques

Conventional laboratory board-producing techniques were used for all boards but the phenolic-bonded hardboard. Hardboard of atmospherically ground fiber normally has the phenolic resin blended with the fiber as the raw material is ground into fiber in the attrition mill. The mill thus simultaneously serves as an attrition mill and blender. Urea resin, having a lower curing temperature, cannot be blended in this way, as it would cure in the dryer. Since it was necessary to use fiber generated in Phase I, the resin had to be added after fiber generation for the study of hardboard.

The procedure used in the laboratory for blending the fiber with the diluted resin-wax mixture was to first blend in a rotary drum blender and then to pass the material through a 24 in. (610 mm) diameter, double-revolving disc attrition mill [plate setting 0.100 in. (2.5 mm)]. Blending in the rotary drum is poor, as the resin is not distributed adequately over the fiber. The subsequent attrition milling, however, accomplishes sufficient distribution so that representative boards can be made.

Because the resin was diluted to 20% to assist with resin distribution, extra moisture was added to the furnish so that the moisture content of the material was higher than desired. This necessitated post-drying of the fiber from about 15% to 8%. Further experimentation may show that this much resin dilution is not necessary, but this was not within the scope of this research.

## Testing

Board properties measured were: MOR, MOE, IB, LE. Testing was conducted as before, following ASTM D 1037 specifications.

The test specimens cut from the door core and structural flakeboard had 0.025 in. (0.6 mm) planed from each face to remove soft surfaces and to simulate sanding. Underlayment and furniture core boards had excellent faces; therefore, simulated sanding was not performed on them. Hardboard is normally not sanded and no sanding was performed in this study. The medium density fiberboards (MDF) made in Phase I and used in this phase of the research as typical MDF boards had their faces planed to remove the soft surfaces that appear inherent in most MDF boards which are cured by platen heating in the press.

## Results and Discussion

The "typical" underlayment, furniture core, door core, structural flakeboard, hardboards, and medium density fiberboard will be discussed individually. Appropriate standards will be used for comparison when applicable. Tables 22 to 24 present the data on the boards produced.

### Underlayment

This product is normally about 0.64 specific gravity. The white pine and lodgepole pine boards averaged about 0.66 in specific gravity. MOR, MOE, and IB values were well above the

Table 22. Average Physical Properties of Underlayment, Furniture Core, and Door Core Boards Produced in Phase II.

| Type of Board | Species | MOR/MOE SG | MOR(psi) | MOE (psi x $10^6$) | IB SG | IB PSI | Response to 90% Relative Humidity Exposure LE(%) | MA(%)** | TS(%) | MC(%) |
|---|---|---|---|---|---|---|---|---|---|---|
| Underlayment | White Pine | 0.66 | 2600 (17.9 MPa) | 0.430 (2964) | 0.66 | 113 (0.78) | 0.28 | 11.4 | 14.4 | 20.0 |
| | Lodgepole | 0.66 | 2490 (17.2) | 0.415 (2861) | 0.65 | 144 (0.99) | 0.43 | 11.9 | 14.2 | 20.7 |
| Furniture Core | White Pine | 0.75 | 4540 (31.3) | 0.608 (4191) | 0.75 | 133 (0.92) | 0.27 | 10.9 | 11.5 | 19.4 |
| | Lodgepole | 0.73 | 4150 (28.6) | 0.580 (3998) | 0.73 | 169 (1.16) | 0.44 | 11.5 | 11.0 | 19.9 |
| Door Core | White Pine | 0.48 | 1390 (9.6) | 0.239 (1648) | 0.49 | 62 (0.43) | 0.31 | 11.8 | 9.5 | 20.5 |
| | Lodgepole | 0.47 | 1300 (8.9) | 0.234 (1613) | 0.50 | 81 (0.56) | 0.44 | 12.4 | 8.7 | 21.2 |
| CS 236-66* | IB1 | 0.59 to | 1600 (11.0) | 0.250 (1723) | 0.59 to | 70 (0.48) | 0.35 | — | — | — |
| | IB2 | 0.80 | 2400 (16.5) | 0.400 (2758) | 0.80 | 60 (0.41) | 0.30 | — | — | — |
| | IC1 | below 0.59 | 800 (5.5) | 0.150 (1034) | below 0.59 | 20 (0.14) | 0.30 | — | — | — |
| | IC2 | | 1400 (9.6) | 0.250 (1723) | | 30 (0.21) | 0.30 | — | — | — |

*Commercial Standard 236-66 "Mat-Formed Wood Particleboard."
**Based on weight of specimens after conditioning at 50% RH.

Table 23. Average Physical Properties of Structural Flakeboard Produced in Phase II.

| | | MOR/MOE | | | IB | | Response to 90% Relative Humidity Exposure | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Species | SG | MOR(psi) | MOE(psi x $10^6$) | SG | PSI | LE(%) | MA(%) | TS(%) | MC(%) |
| | White Pine | 0.74 | 3440 (23.7 MPa) | 0.570 (3929) | 0.75 | 51 (0.35) | 0.13 | 13.4 | 20.9 | 21.3 |
| | Lodgepole | 0.75 | 3480 (24.0) | 0.580 (3998) | 0.77 | 67 (0.46) | 0.20 | 13.6 | 20.3 | 21.3 |
| CS 236-66* | 2B1 | 0.59 to 0.80 | 1800 (12.4) | 0.250 (1723) | 0.59 to 0.80 | 65 (0.45) | 0.35 | — | — | — |
| | 2B2 | 0.59 to 0.80 | 2500 (17.2) | 0.450 (3102) | 0.59 to 0.80 | 60 (0.41) | 0.25 | — | — | — |

*Commercial Standard "Mat-Formed Wood Particleboard."

Table 24. Average Physical Properties of Hardboard Made from Atmospheric-and Pressure-Refined Fiber.

| | | MOR/MOE | | | IB | | Response to 90% Relative Humidity Exposure | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Process | Species | SG | MOR(psi) | MOE(psi x $10^6$) | SG | PSI | LE(%) | MA(%) | TS(%) | MC(%) |
| Atmospheric-Refined | White Pine | 0.93 | 6830 (47.1 MPa) | 0.527 (3633) | 0.92 | 196 (1.35) | 0.23 | 9.8 | 11.4 | 15.9 |
| | Lodgepole | 0.94 | 6490 (44.7) | 0.489 (3371) | 0.93 | 225 (1.55) | 0.45 | 9.9 | 10.6 | 16.1 |
| Pressure-Refined | White Pine | 1.00 | 9200 (63.4) | 0.657 (4529) | 0.99 | 211 (1.45) | 0.28 | 9.3 | 10.0 | 14.8 |
| | Lodgepole | 1.01 | 10200 (70.3) | 0.689 (4750) | 1.01 | 290 (1.99) | 0.39 | 9.5 | 10.5 | 15.4 |
| PS 58-73* | Standard Board ( ) | 0.50 or greater | 5000 (34.5) | — | 0.50 or greater | 100 (0.69) | — | — | — | — |

*Voluntary Product Standard "Basic Hardboard." (PS 58-73)

particleboard commercial standard for boards of this general type-grade-class (Commercial Standard CS 236-66). Type refers to the resin used (1 means interior resin, such as urea), grade stands for density level, and class stands for strength classifications. For example, a 1B1 board is made with interior resin, is between 0.59 and 0.80 in specific gravity, and is a class 1 board.

Linear expansion for the white pine boards was below the specified maximum for 1B1 and 1B2 boards, respectively. The lodgepole boards were above the specified limitations. Further adjustment of the particle mixture, or improvement of the particle geometry, could conceivably improve LE.

As noted previously for the Phase I boards, higher moisture contents than expected were observed in that work after exposing the LE specimens in the 90% RH atmosphere. This same trend was observed throughout the boards made in this phase covering typical commercial boards. The underlayment, furniture core, door core, and structural flakeboards averaged between 19.4% and 21.3% in moisture content at equilibrium with the 90% RH condition. The *Wood Handbook* notes that the equilibrium moisture content of wood conditioned at 90% RH is 20.5%. This is an extremely difficult test atmosphere to maintain, and some minor fluctuations of conditions may have been taking place. It appears more likely that the two species being studied absorbed slightly more moisture than the working value of 20.5% listed in the *Wood Handbook* for all species.

## Furniture Core

Furniture core or industrial board will usually be found at specific gravities of about 0.72 and above and at higher resin levels than underlayment board. The white pine boards averaged 0.75 specific gravity and the lodgepole pine 0.73. Compared to industrial boards commonly found, from experience the MOR, MOE, and IB values were excellent. As in the underlayment boards, the lodgepole pine boards were above the commercial standard specification for LE and the white pine was below.

## Door Core

Door core is a low density product made at specific gravities of about 0.47. The boards produced were at this specific gravity level or close to it. MOR, MOE, and IB values were far above the 1C1 specifications. However, MOR and MOE values were below 1C2 specifications. Internal bond, on the other hand, was double that required by the specification. Introduction of some thin flakes into the face furnish may be necessary to improve bending and stiffness

properties. The use of a ring-refiner to prepare small thin particles for use on the faces would also likely improve the MOR and MOE. Such particles have better length/thickness ratios, which assist in developing the better properties.

As with the other particleboards, white pine was lower in LE than lodgepole pine. This indicates an interaction which may be inherent within the species. Boards of lodgepole pine may have a greater LE as a species, as Heebink's paper shows an LE value of 0.53% for similar boards of lodgepole (3). Both species, however, were above the property requirements listed in the commercial standard.

## Structural Flakeboard

Some problems were observed in making what is being called structural flakeboard for this study. It is difficult to cut quality flakes from dry wood. Since the dead class material was dry, this problem could not be avoided.

Problems occurred in obtaining reasonably good IB's with a one minute press closing. MOR values for lodgepole pine were about 3800 psi (26.2 MPa) and MOE values were about 460,000 psi (3172 MPa), but internal bond was low at 52 psi (0.36 MPa). This low IB value falls below the commercial standard requirements for boards bonded with exterior type resins.

The press closing time was then changed to two minutes in order to densify the board core and improve IB. As shown in Table 23, boards of lodgepole pine then barely met the particleboard requirements of 65 psi (0.45 MPa) for 2B1 boards and 60 psi (0.41 MPa) for 2B2 boards. White pine boards fell below these levels.

The increased closing time, while improving core density, decreased board face density. Thus, a soft surface was developed which had to be planed off before testing. For some structural flakeboards, the extra step of sanding would be undesirable because of the extra cost. MOR and MOE values were well above the specifications of the commercial standard. Board density was slightly higher than intended. Thus, board properties, particularly IB, would be decreased if boards were made at a lower density.

LE values were low, as would be expected from flakeboards. The white pine again had the lowest LE.

Microscopic examination of some of the dead and live class flakes showed an excellent surface quality with live material but a poor surface quality for the dead. Flakeboards normally have the lowest IB's because of only laminar bonding and not edge-to-edge bonding as well,

which is found with shavings and hammermilled particles that intermesh better in a board. Thus, poor surfaces for bonding have a far greater deleterious effect on internal bond of flakeboards than with hammermilled particleboard or other such boards.

## Hardboard

Hardboards produced from both atmospheric- and pressure-refined fiber had excellent properties, even though the boards of atmospheric-refined fiber were lower in density than intended. The 3% resin level was arbitrarily selected for this work, and it is obvious that a much lower resin level could be used.

LE requirements are not included in the standard for basic hardboard. Measurements taken in this study show white pine boards expanding less than lodgepole pine boards, which was the same relationship previously observed with particleboards.

## Medium Density Fiberboard

There are two standards at present for medium density fiberboard. In the first, "Basic Hardboard," MDF is designated as "Industrialite" board. The second standard is NPA 4-73 "Medium Density Fiberboard." Table 25 presents data for 0.72 specific gravity boards, which was taken from the linear regression lines developed in the Phase I research for the medium-density fiberboards produced at the 0.65 and 0.85 specific gravity levels. The 0.72 specific gravity level was selected because this is a popular density in use in industry.

The boards of both white pine and lodgepole met the specifications of both standards in MOR, MOE, and IB. LE for these boards was discussed earlier, and the problems encountered with this test makes it difficult to assess the correct LE properties of these panels at this time.

## Phase 2 Conclusions

Typical commercial boards of dead class material showed excellent overall properties. Underlayment boards had good properties except for excessive LE in lodgepole pine. This higher LE over white pine was observed throughout this part of the research and was attributed to a species effect.

Table 25. Average Physical Properties of Medium Density Pressure-Refined Fiberboard.

| | MOR/MOE | | | IB | |
|---|---|---|---|---|---|
| Species | SG | MOR (psi) | MOE (psi x $10^6$) | SG | PSI |
| White Pine | 0.72 | 3800 (26.2 MPa) | 0.350 (2413) | 0.72 | 135 (0.93) |
| Lodgepole | 0.72 | 4400 (30.3) | 0.400 (2757) | 0.72 | 110 (0.76) |
| NPA 4-73* Medium Density Fiberboard | 0.48 to 0.80 | 3500 (24.1) | 0.300 (2068) | 0.48 to 0.80 | 100 (0.69) |
| PS 58-73** Class 5 "Industrialite" | 0.50 or Greater | 2000 (13.8) | - | 0.50 or Greater | 35 (0.24) |

*National Particleboard Association Standard NPA 4-73, "Medium Density Fiberboard."

**Voluntary Product Standard PS 58-73, "Basic Hardboard."

Furniture-core boards had superior properties. Door core had excellent IB, and 1C1 particleboard requirements were met for MOR and MOE. However, requirements for 1C2 boards were not met for bending and stiffness. LE minimums were exceeded for both 1C1 and 1C2 boards, with white pine barely exceeding the minimums.

Good MOR and MOE values were observed in structural flakeboards. It was difficult to achieve IB values meeting the commercial standard requirements. Poorer quality flakes, due to flaking dead, dry material, apparently were responsible for the low IB. Because of the favorable flake geometry, LE was the lowest for any type of board made.

Excellent dry process hardboards were made from both atmospheric- and pressure-refined fiber. A reduction in the 3% resin level used should be possible while still meeting appropriate standards.

Medium density fiberboards had good IB, MOR, and MOE properties. Some problems occurred in measuring LE, making it difficult to assess this property.

## References

1. U.S. Forest Service. 1974. *Wood Handbook: Wood as an Engineering Material*. U.S. Government Printing Office, Washington, D.C. Table 4-2.

2. McVey, D. T. 1968. "A Description of the Laboratory Method Used in Measuring the pH and Buffer of Wood." *Proceedings of Second WSU Symposium on Particleboard*. Washington State University, Pullman, Washington. pp. 137-138.

3. Heebink, B. G. 1974. *Particleboards from Lodgepole Pine Forest Residue*. USDA Forest Service Research Paper FPL 221.

★ U.S. Government Printing Office: 1977-779-815/221 Region 8